NEW

Everything you want to know about the world we live in

HOW IT WORKS Annual

1000s OF AMAZING FACTS INSIDE

Digital Edition

FUTURE

VOLUME 12 EDITION

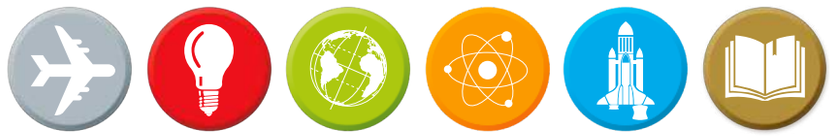
SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

WELCOME TO HOW IT WORKS Annual

Welcome to the How It Works Annual, a carefully curated compilation of our favourite new How It Works features. As ever, they're packed with eye-catching illustrations, expert interviews, and mind-blowing facts.

We've picked the topics we think you will love from across our six categories: science, environment, technology, history, space, and transport. Learn all about your DNA and how it makes you the unique individual you are; see how amateur fossil hunters made an incredible new dinosaur discovery on the south coast of England - and what you need to start your own fossil hunting hobby. Discover the science behind food going bad, what the European Space Agency does to protect the planet from rogue asteroids and falling satellites, discover sunken cities, how microchips are made, explore the historic 10 Downing Street residence of the UK's prime minister, how the navy builds warships, and much more.

Don't forget to have your smartphone or compatible device ready while you're reading, because we've packed this issue with augmented reality 3D pictures that will bring the magazine to life. Enjoy!




FUTURE

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SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

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AR ZONE!

Scan the QR code with your device's camera or download a free QR code reader app. Many iPhone and Android devices include a QR reader

When you see the AR ZONE! logo at the top of a page, use your phone to scan the QR code, which looks like this

Hold your mobile device over the image and watch it come to life! Your device needs to be connected to the internet for this to work

HOW THE AUGMENTED REALITY WORKS

After being launched by the QR code, the app reads anything you point your device's camera at 30 times a second, searching for distinctive shapes we've trained it to recognise. When it sees a familiar picture, it overlays the augmented-reality 3D image we've previously uploaded on your screen.

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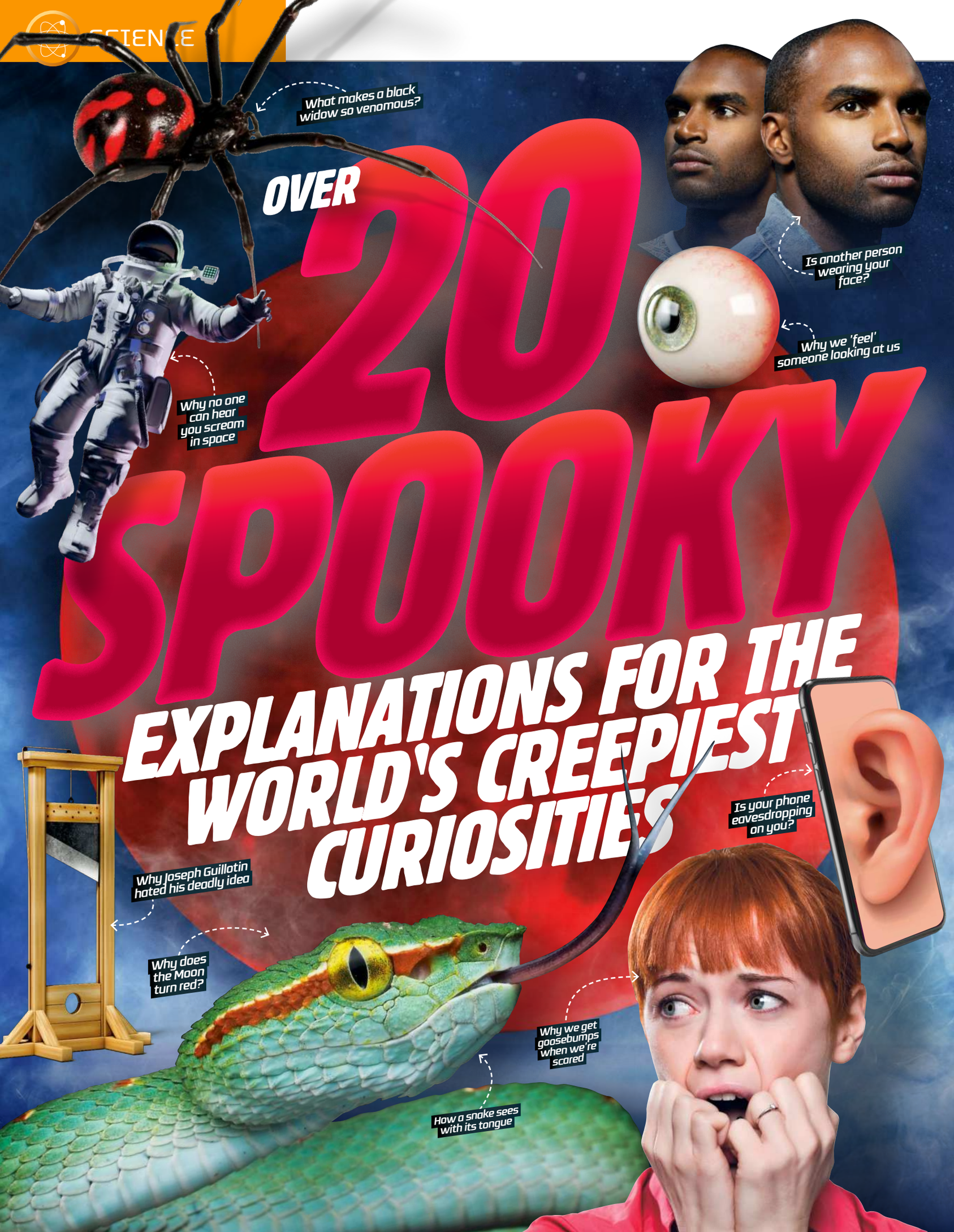
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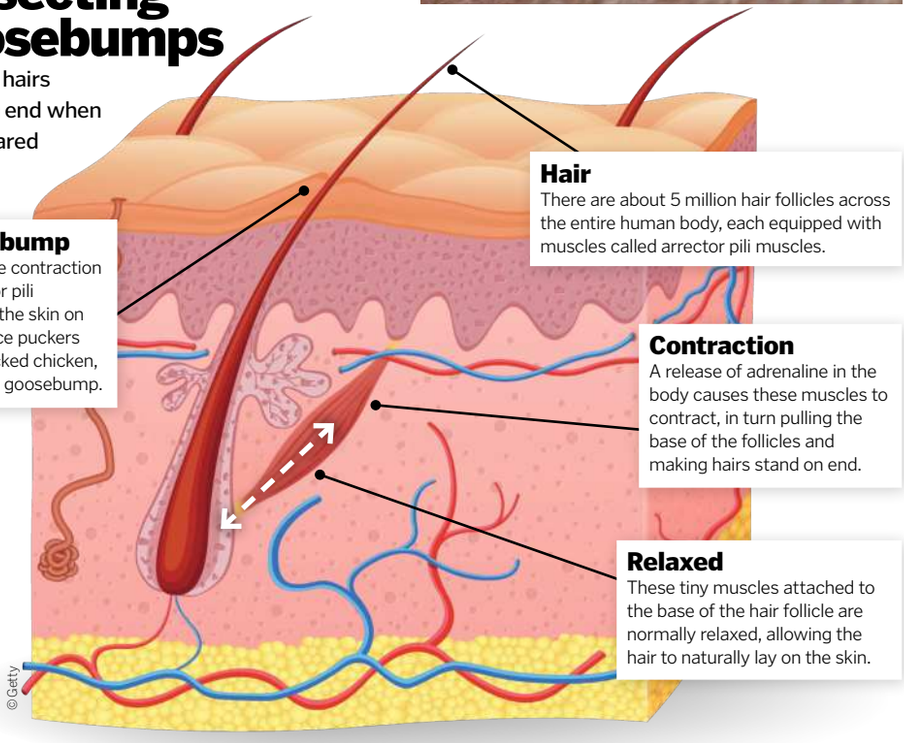
WHY DO WE GET GOOSEBUMPS WHEN WE'RE SCARED?

Sitting at home, alone and in the dark, a sudden sense of fear and a swift chill may wash over your body. Sure enough, your hairs stand to attention and goosebumps cover your skin. It's a sensation we've all felt at one time or another, but why does our body react in this way when we're scared? It harkens back to a time when ancient humans faced the daily fear of life-threatening predators. As a result our bodies evolved what we now call a fight-or-flight response. This is a stress response which triggers a release of adrenaline, causing our heart race to rush, our palms to sweat and goosebumps to appear. During this state of fight or flight, the tiny muscles adjacent to each hair contract, making hairs stand on end. Today humans are relatively hairless compared to our animal ancestors. Charles Darwin postulated that at one point in time our ancestors would have been a great deal hairier, and goosebumps would have puffed out their hair to make them look bigger and appear more intimidating to potential predators.

Goosebumps can also help to prevent the loss of heat when we feel cold

Dissecting goosebumps

How our hairs stand on end when we're scared

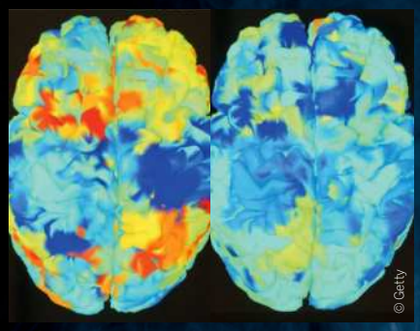


Goosebump
During the contraction of arrector pili muscles, the skin on the surface puckers like a plucked chicken, forming a goosebump.

Hair
There are about 5 million hair follicles across the entire human body, each equipped with muscles called arrector pili muscles.

Contraction
A release of adrenaline in the body causes these muscles to contract, in turn pulling the base of the follicles and making hairs stand on end.

Relaxed
These tiny muscles attached to the base of the hair follicle are normally relaxed, allowing the hair to naturally lay on the skin.



Brain patterns were observed using a functional magnetic resonance imaging (fMRI) machine

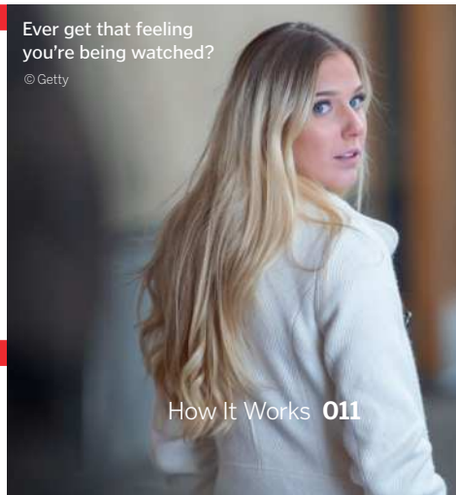
IS MIND-READING POSSIBLE?

Our thoughts are our most private and personal belongings, and the idea that someone could go snooping around inside our heads is terrifying. However, the technology to do so is being developed. Besides the moral and ethical hurdles of mind-reading, the brain is an extremely complex organ. Taking it one step at a time, researchers have been analysing the electrical patterns we produce in the brain when we think of something, such as an object, number or even a sentence. The researchers can then identify and decipher distinct patterns associated with those thoughts in the hope of building a neural dictionary of patterns.

The technology is still in its relative infancy, with years of development needed before complex thoughts can be interpreted. Currently this is being developed to offer insights into the way our brains work, rather than for alternative medical treatments. However, the potential of mind-reading technology is wide-reaching. From understanding autism to predicting a person's decision-making, once you can peer inside the mind, the possibilities are endless.

HOW DO YOU KNOW WHEN SOMEONE IS WATCHING YOU?

Do you ever get a nagging feeling that someone is staring at you? Is it really possible for us to have a six sense of when we're being watched? Studies have found that a single brain cell fires signals when someone looks at us, stopping when their gaze moves away. This was put to the test in 2013 on a patient with cortical blindness. The patient's visual cortex in the brain was damaged, but the brain still received information from the eyes. What was interesting was that the region of the brain that responds to potential threats, called the amygdala, became active when someone stared at the patient. This innate six sense most likely evolved in ancestral humans as a way to detect when a predator was nearby, giving them the chance to escape.


Ever get that feeling you're being watched?
© Getty

WHAT IS LURKING AT THE BOTTOM OF THE OCEAN?

Fewer people have seen the deepest parts of our oceans than have walked on the Moon, so our knowledge of what swims in the deep blue is relatively small. The deepest region of the ocean is called the hadal zone, which begins around six kilometres below the surface. This largely unexplored region consists of trenches formed by Earth's tectonic plates and is inhabited by marine life that can withstand its extreme pressures and lack of sunlight. Some crustaceans and even species of fish, such as the hadal snailfish, have been observed in the zone as deep as eight kilometres below the surface.

A squat lobster found in th e Mariana Trench, the deepest part the ocean

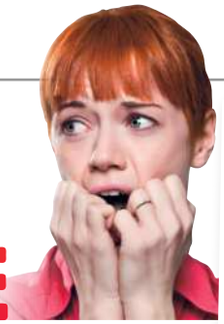
WHAT CAUSES A BLOOD MOON?

Every year or so our lunar neighbour rises in the sky with an eerie crimson glow, known as a blood Moon. It's a phenomenon that typically happens around May, and occurs during a lunar eclipse. This is similar to a solar eclipse, whereby the Moon and Sun perfectly align, blocking our view of the Sun. During a lunar eclipse, however, it is Earth that is blocking most sunlight from the Moon. Any light that does make it to the surface of the Moon passes through Earth's atmosphere. As the visible spectrum of light travels through our atmosphere, blue wavelengths are scattered, leaving red wavelengths to journey to the Moon and giving it a reddish hue. Throughout the year there are other occasions when the Moon appears ruddy, and they're often mistaken for a true blood Moon – this is due to pollution, cloud cover or debris in the atmosphere.

The next blood Moon will occur on 26 May 2021

© Getty

WHY DO WE HAVE NIGHTMARES?



Typically people dream for around two hours a night. During this portion of rest, called rapid eye movement (REM) sleep, is when nightmares can creep in. Sometimes referred to as 'threat rehearsal', it's believed that nightmares occur to prepare us for the possible dangers we might face in real life, although many nightmares are stress-related. At some point during human evolution nightmares may have served a purpose in bringing real-world dangers to our attention and keeping us alert to potential threats. However, in a world where we're no longer chased by prehistoric predators or battling the elements, do nightmares still have a role to play?

Losing your teeth is one of the most common nightmares

Although the dangers that may have birthed this neurological function are long forgotten, modern threats such as house fires, car crashes and murder keep nightmares alive. There is, however, a way to battle against them before you head to bed. Some suggest rehearsing an alternative ending to any recurring nightmares while awake, and trying to understand any reasons behind your nightmares is paramount.

Inside the nightmare

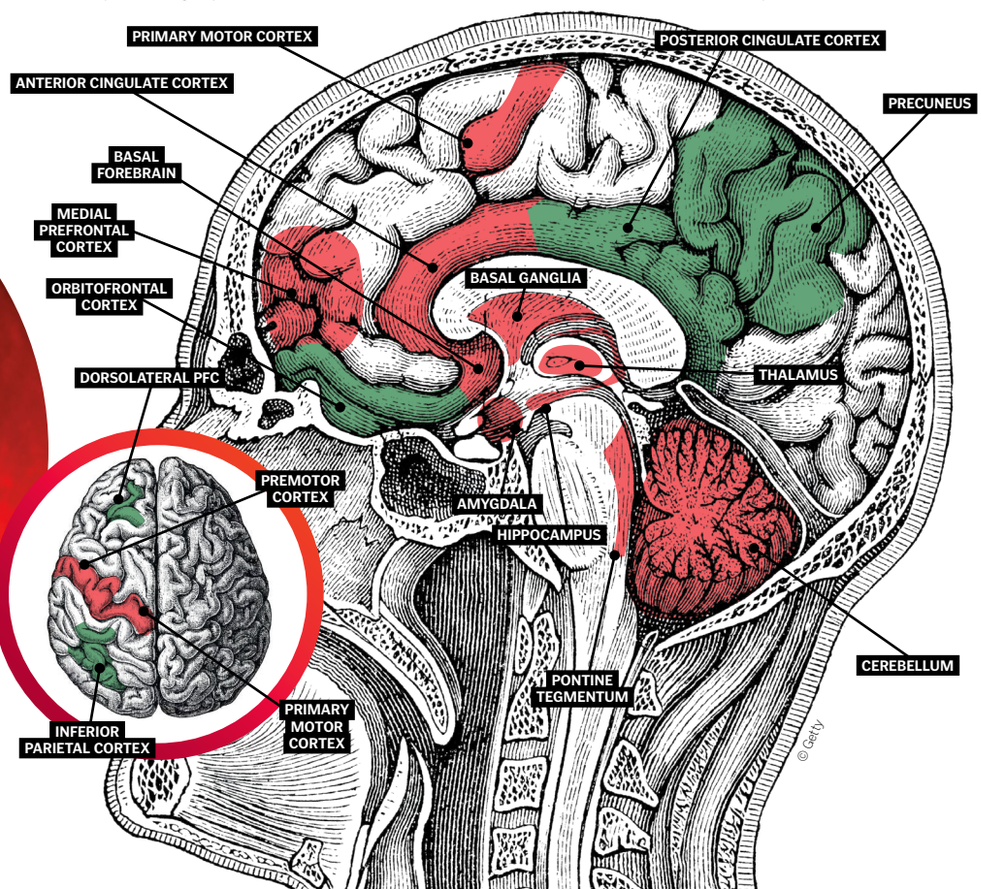
What regions of the brain are awake while we dream?

Activated

There are several regions of the brain that are active during REM sleep which have different roles when considering their functions while dreaming. Regions such as the cerebellum, basal ganglia and premotor cortex are linked with the motor content of our dreams. These regions are responsible for creating the sensation of movement, like running from an intruder during a nightmare. Other regions such as the thalamus and basal forebrain are linked to the emotion-processing aspects of our dreams.

Deactivated

While many regions are activated to produce dreams and nightmares, some are deactivated to allow them to occur. For example, regions of the prefrontal cortex and inferior parietal cortex are typically involved in cognitive control, perception of time and space and self awareness. This allows us to drift off into a dream unaware of our physical bodies. The deactivation of these regions is also thought to contribute to the reason we don't often remember our dreams when we wake up.



Inside the venom

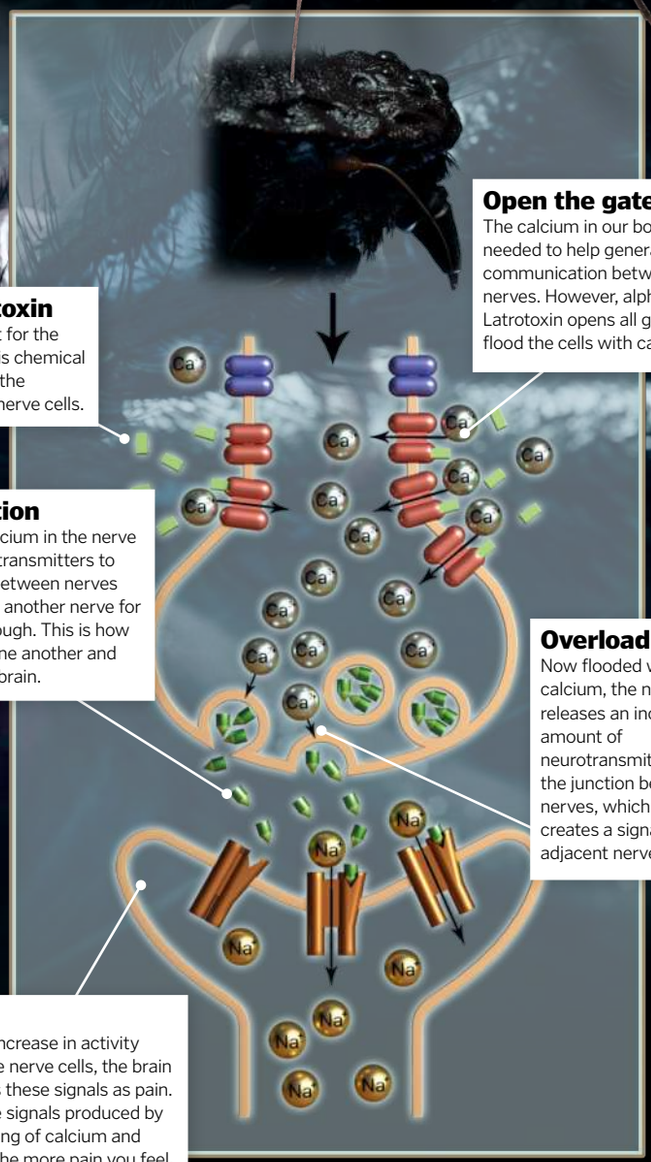
How black widow venom causes excruciating pain

Venom gland
Venom is produced and stored in a small sack at the front of the spider's head.

Alpha-latrotoxin
As the main culprit for the causing of pain, this chemical embeds itself into the membrane of our nerve cells.

Communication
The presence of calcium in the nerve cells triggers neurotransmitters to cross the junction between nerves and opens gates on another nerve for sodium to pass through. This is how nerve cells talk to one another and send signals to the brain.

Venom canal
When the spider is threatened the venom will travel from the venom gland, down the venom canal and into the fang, passing into its victim.



Open the gates
The calcium in our bodies is needed to help generate communication between our nerves. However, alpha-Latrotoxin opens all gates to flood the cells with calcium.

Overload
Now flooded with calcium, the nerve releases an increased amount of neurotransmitters in the junction between nerves, which then creates a signal in the adjacent nerve.

Pain
With an increase in activity within the nerve cells, the brain perceives these signals as pain. The more signals produced by the flooding of calcium and sodium, the more pain you feel.

WHY IS BLACK WIDOW SPIDER VENOM SO POTENT?

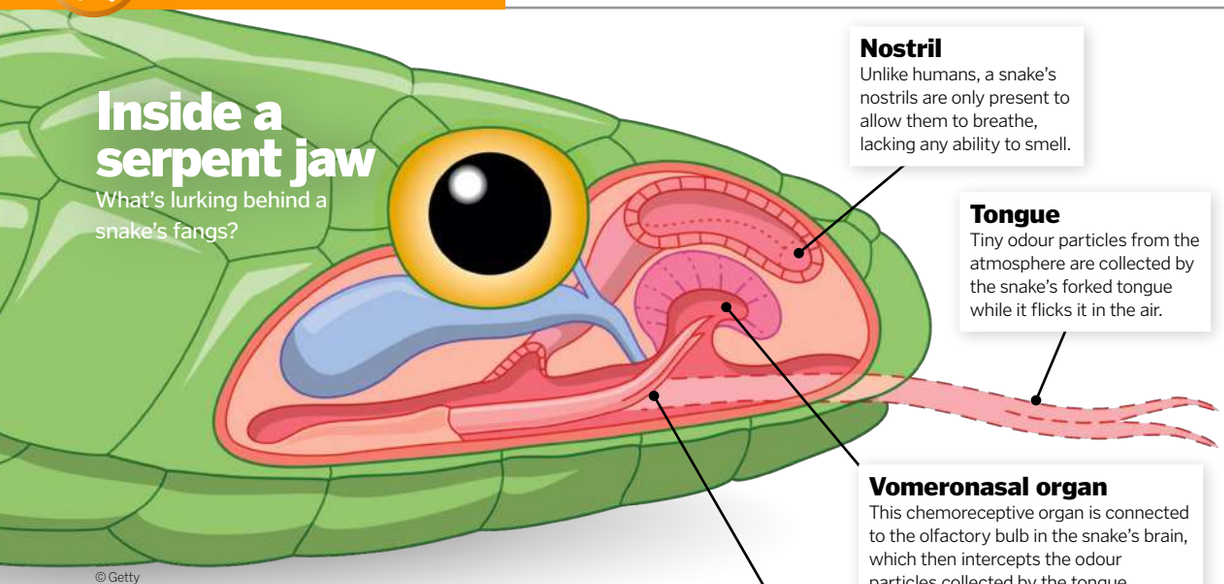
Striking fear into the hearts of those that spot the tiny red markings on an otherwise ordinary-looking spider, black widows are some of the most venomous creatures on Earth. This accolade has led to many believing this spider to be an aggressive insect. In reality these spiders are shy and they only attack humans when their bodies have been pinched or accidentally squashed.

However, when they do strike it wreaks havoc on the human nervous system. What makes their bite so agonising is the presence of a neurotoxin called alpha-latrotoxin. This neural hijacker causes rampant pain throughout the victim's nervous system. However, it's a common misconception that a single bite from a black widow spider is always a death sentence. Fatality is rare in healthy humans, with most recovering with medical assistance in 24 hours. Young children and those who are ill or elderly are at the highest risk.

Black widows are found in temperate regions around the world

Inside a serpent jaw

What's lurking behind a snake's fangs?



Nostril
Unlike humans, a snake's nostrils are only present to allow them to breathe, lacking any ability to smell.

Tongue
Tiny odour particles from the atmosphere are collected by the snake's forked tongue while it flicks it in the air.

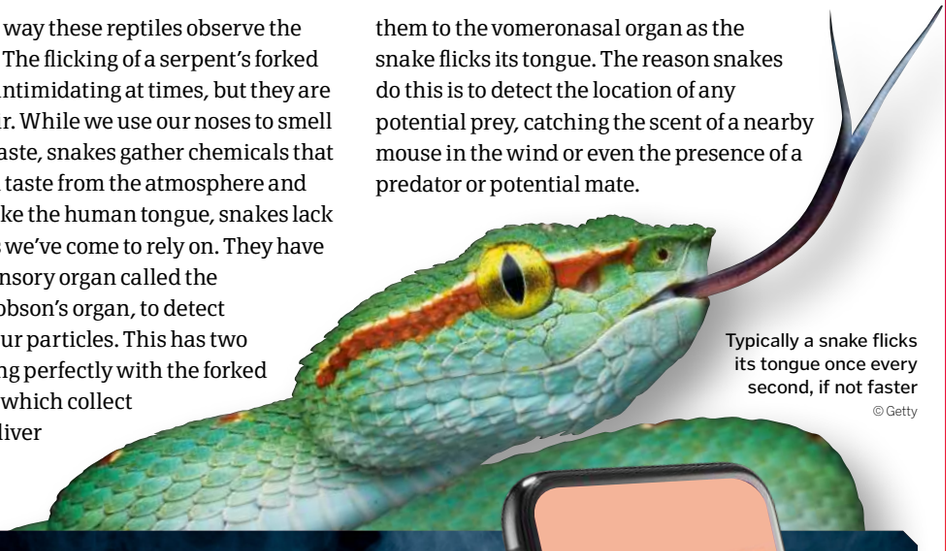
Vomeronasal organ
This chemoreceptive organ is connected to the olfactory bulb in the snake's brain, which then intercepts the odour particles collected by the tongue.

Retraction
Odour particles are mixed with the fluids inside the snake's mouth as the tongue retracts.

© Getty

WHY IS A SNAKE'S TONGUE FORKED?

It's all to do with the way these reptiles observe the world around them. The flicking of a serpent's forked tongue might seem intimidating at times, but they are simply tasting the air. While we use our noses to smell and our tongues to taste, snakes gather chemicals that pertain to smell and taste from the atmosphere and interpret them. Unlike the human tongue, snakes lack the many taste buds we've come to rely on. They have instead evolved a sensory organ called the vomeronasal, or Jacobson's organ, to detect moisture-borne odour particles. This has two holes – corresponding perfectly with the forked ends of the tongue – which collect the particles and deliver them to the vomeronasal organ as the snake flicks its tongue. The reason snakes do this is to detect the location of any potential prey, catching the scent of a nearby mouse in the wind or even the presence of a predator or potential mate.

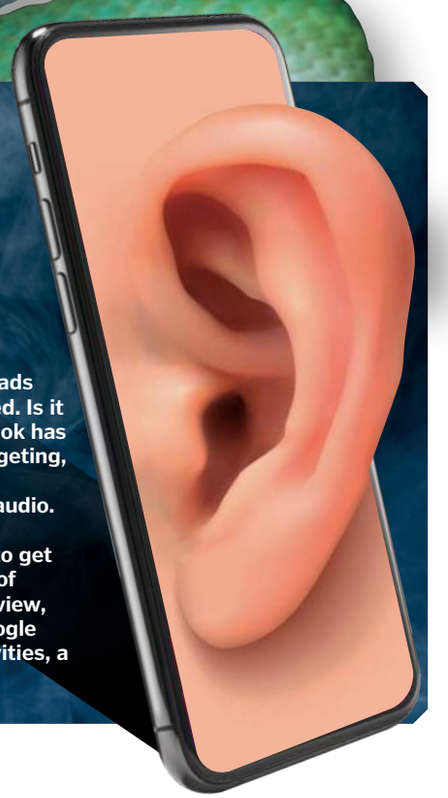


Typically a snake flicks its tongue once every second, if not faster

© Getty

IS YOUR PHONE EAVESDROPPING ON YOU?

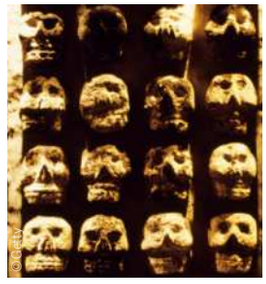
It seems oddly serendipitous when, after a conversation, online ads begin recommending brands of products you may have discussed. Is it a coincidence, or is your phone secretly listening to you? Facebook has repeatedly stated that its app does not listen to users for ad-targeting, though some sources report that many apps have permission to activate our microphones and the ability to analyse snippets of audio. In the grand scheme of things, however, listening in on our conversations for targeted ads isn't the most effective method to get relevant information – especially when you consider the wealth of information our digital footprints can provide, such as what we view, like or share on social media, or the cookies gained from our Google search history. It's far more likely that your previous online activities, a tweet or Facebook post has sparked an ad.



WHY DID THE AZTECS SACRIFICE HUMANS?

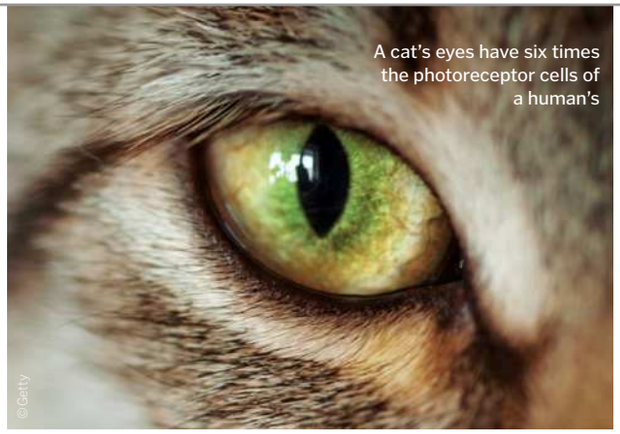
Standing over a stone altar at a temple summit, an Aztec priest raises his obsidian blade before plunging it into the chest of the body laying before him, allowing the blood of the human sacrifice to cascade down the temple steps. It's a scene well documented throughout history when you delve into the traditions and rituals of the Aztecs, who lived between the 14th and 16th century.

Many Spanish conquistadors recorded seeing such bloodthirsty rituals, and even detailed a rack of 130,000 skulls of the victims called a tzompantli. It wasn't until 2015 that this enormous and terrifying edifice was excavated by archaeologists, revealing the secrets of human sacrifice. It's thought that humans were offered as nourishment to the Aztec gods to ensure that the Sun would rise and to allow prosperity for the people. Those that evaded the sacrificial altar were not the only ones thought to prosper from sacrifice. Those that felt the sharp edge of the knife were believed to gain an honoured place in the afterlife.



© Getty

The skull rack found during the excavations of the Aztec Templo Mayor, Tenochtitlan



A cat's eyes have six times the photoreceptor cells of a human's

© Getty

WHY ARE CAT PUPILS VERTICAL?

As fierce hunters, cats and other nocturnal predators have evolved vertically slit pupils as a way to better ambush their prey at night. To successfully seek out their prey, cats need to be excellent at gauging the depth and distance of their next meal. This is where having a vertical pupil comes in handy. Researchers have found that predators such as snakes, cats and crocodiles are better at depth perception and can easily focus on their targets.

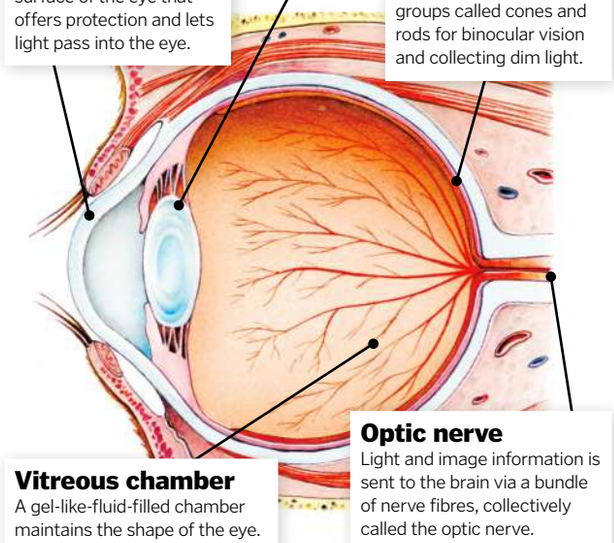
Look inside the eye

Cats are among the sharpest-eyed mammals

Lens
The lens changes shape to focus light into the retina.

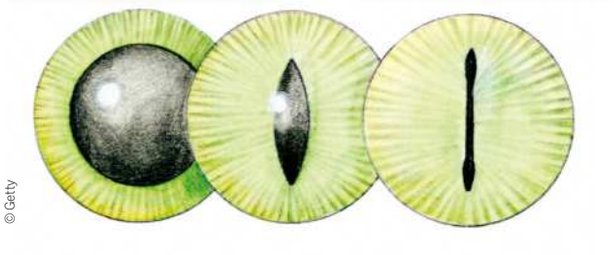
Retina
Within the retina are cells that can detect light, called photoreceptors, which are split into two groups called cones and rods for binocular vision and collecting dim light.

Cornea
The dome at the front surface of the eye that offers protection and lets light pass into the eye.



Optic nerve
Light and image information is sent to the brain via a bundle of nerve fibres, collectively called the optic nerve.

Vitreous chamber
A gel-like-fluid-filled chamber maintains the shape of the eye.



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WILL THE SUN ENGULF EARTH?

As our Sun expands towards the end of its life, the planets in its path will ultimately meet their doom. Earth is in the firing line, but not for a long time. In around 5 billion years the Sun will start to swell into a red giant, engulfing Mercury and Venus, then Earth. However, long before it swallows our planet, the heat generated from the giant fireball will boil the oceans and kill all life on Earth. In around 7.5 billion years the Sun will have used up 33 per cent of its current mass, weakening its gravitational hold on Earth and sending our planet into an expanded orbit. This may not be enough to save Earth, with many physicists predicting it will meet the same fate as Mercury and Venus.

IS SPONTANEOUS HUMAN COMBUSTION POSSIBLE?

The idea of spontaneously erupting into flames without any prior warning is a harrowing concept, but luckily it's one unsubstantiated by science. As a prevalent theme in fiction during the 1800s, novels such as Charles Dickens' *Bleak House* brought forth the terrifying idea that at any time one of us might suddenly ignite and perish.

Following this idea were claims of real-life occurrences. However, only a handful have ever been formally investigated. Each incident involved elderly victims whose remains were found near open flames such as candles or smoking cigarettes. The fatal flaw in the idea of spontaneous human combustion is in our biology. The human body is made up of 60 to 70 per cent water, a natural enemy of fire. If an internal fire should ignite, our bodies would extinguish it.

Descriptions of spontaneous human combustion date back as far as the 17th century

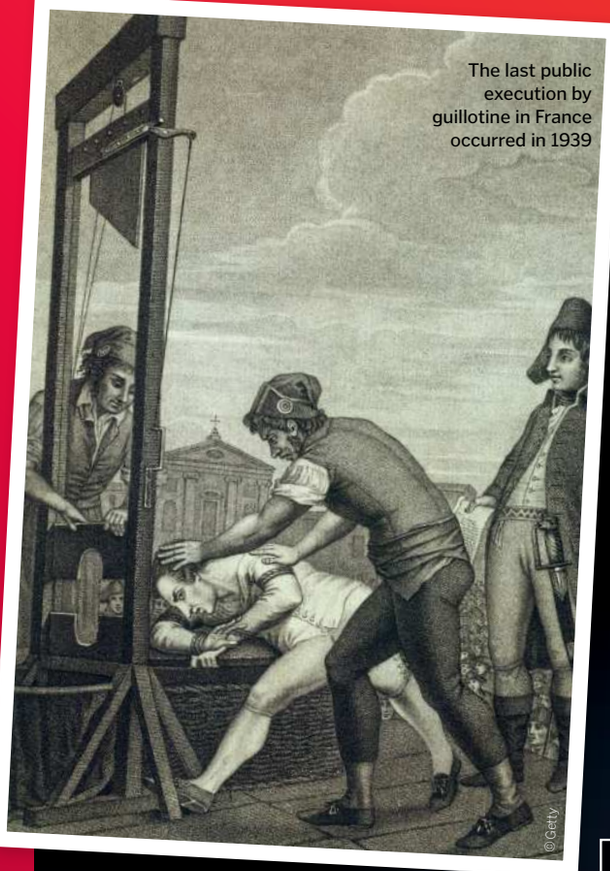
© Alamy

© Getty

WHAT IS DARK MATTER?

Looking out into the abyss of space might leave you wondering why the universe is dominated by darkness. It's believed that the universe is made up of roughly 80 per cent dark matter, a mysterious material which does not emit energy or light.

Although we aren't sure what it is made of, leading the pack as a potential candidate are weakly interacting massive particles (WIMPs), which have a hundred times the mass of a proton but are extremely difficult to detect.



The last public execution by guillotine in France occurred in 1939

WHO INVENTED THE GUILLOTINE?

It may surprise you to discover that anatomy professor Joseph-Ignace Guillotin proposed the guillotine as a gentler method of execution. Guillotin believed that swift decapitation by a blade would be more humane than a sword or axe swung by an executioner. The first life to be officially claimed by a prototype guillotine occurred in France in 1792, designed by French doctor Antoine Louis.

This new form of execution was given the name guillotine after Guillotin's recommendation. However, it's believed that he was against capital punishment and was horrified by the device's name. The guillotine was used until 1981 when the death penalty was abolished, during which time it became a major spectator event and was deemed high entertainment, with souvenirs sold at executions and programmes listing the names of those being executed that day. The guillotine even became a popular children's toy, while novelty devices were sold as vegetable and bread slicers.

Behind the blades

How does a guillotine work?

Wheels
Between the rope and the wooden frame, a series of wheels allowed the executioner to release and raise the blade.

Blade
Made from steel, the angular blade had serrated edges. Together with the mouton, it weighed around 40 kilograms.

Mouton
A piece of metal that secured the blade in place and offered extra weight to drive the blade as it fell.

Restraint
The victim was held between two wooden slats, called a lunette, to secure the head in place.

Declic
This is the lever the executioner would pull to release the blade, to decapitate the victim.

IS SOMEONE OUT THERE WEARING YOUR FACE?

With over 7 billion people on the planet, there is surely going to be someone that shares enough of our facial features to be deemed our doppelganger. We seem to have an odd fascination with finding them and alerting others to their existence: "I saw your double in the supermarket the other day." However, the chances of actually finding one are relatively slim. A 2015 study found that there is a one in 135 chance that someone shares enough facial features to be deemed a doppelgänger. The figure was calculated by comparing eight distinct facial features of 4,000 different people. Researchers found that finding a doppelganger with all eight matching features was a one in a trillion chance.


Could there be someone with the same face as you?

© Getty

COULD A SCREAM BE HEARD IN SPACE?

In the vast vacuum of space, the sound of a lone scream isn't something that can be heard. Not just because the human body would erupt if exposed to space, but for sound waves to travel they need a medium – solid, liquid or gas – to move through. For example, when the skin of a drum is struck, vibrations cause a chain reaction of moving air molecules, pushing them together and creating a sound wave. In space no such medium exists. That's not to say that sound can't travel through space at all – it can, but very inefficiently – so if you find yourself screaming in space, no one will hear you.


© Getty

Sound needs a medium to travel through

5 FACTS ABOUT FAMOUS PRISONERS OF THE TOWER OF LONDON

Source: Wiki/ XXXX

1 Anne Boleyn
King Henry VIII's second wife was imprisoned at the tower, falsely accused and convicted of adultery, incest and treason. On 19 May 1536 she was executed, beheaded by the blade of sword.


Source: Wiki/ XXXX

2 Guy Fawkes
As a chief conspirator in a plot to blow up parliament, Fawkes met his end on 31 January 1606 after being imprisoned in the tower. As he was walking onto a hanging platform, Fawkes jumped from the ladder, breaking his neck and dying.


Source: Wiki/ XXXX

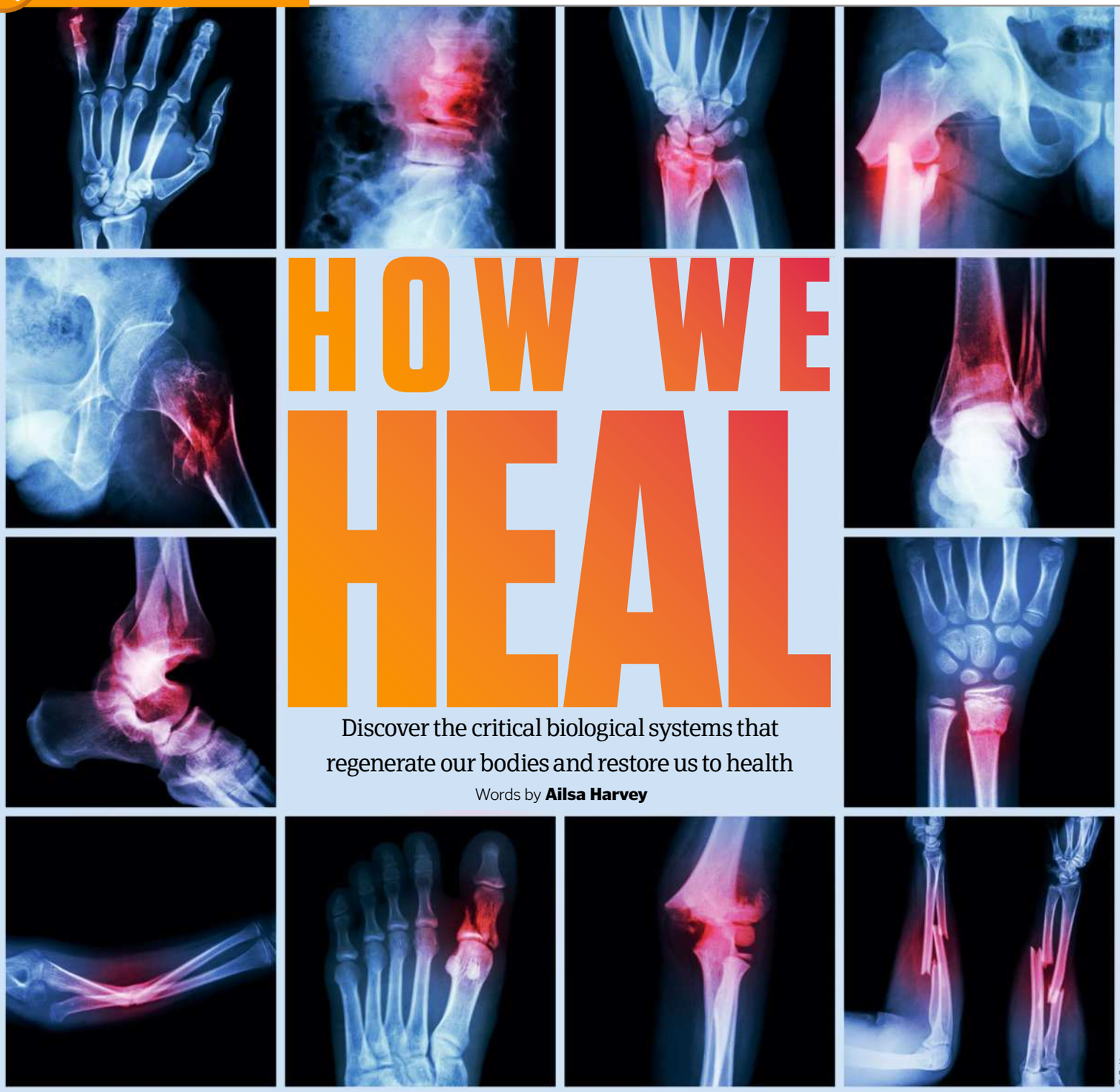
3 Queen Elizabeth I
Queen Mary I believed Princess Elizabeth was plotting against her, ordering her incarceration in 1554. A lack of evidence for Mary's theory resulted in her release after a couple of months.


Source: Wiki/ XXXX

4 Lady Jane Grey
She was queen for just nine days after her father-in-law John Dudley persuaded a dying King Edward VI that Jane should be chosen as his successor. Deposed by the legitimate heir Mary, her and her husband were imprisoned in the tower and executed in 1554.


© Getty

5 The Kray Twins
As the last prisoners in the tower, these London gangsters were notorious murderers and thieves. However, these were not the crimes that landed them in the tower, but for assaulting a corporal after failing to report for national service with the Royal Fusiliers.



HOW WE HEAL

Discover the critical biological systems that regenerate our bodies and restore us to health

Words by **Ailsa Harvey**

Every day we use our bodies as tools. Our legs transport us to where we need to be, our fingers can feel and manipulate the objects we hold and our insides work like engines to churn out the energy we need to live. It can be easy to forget about each precise function our bodies provide until one of them fails, becoming fragile or unusable.

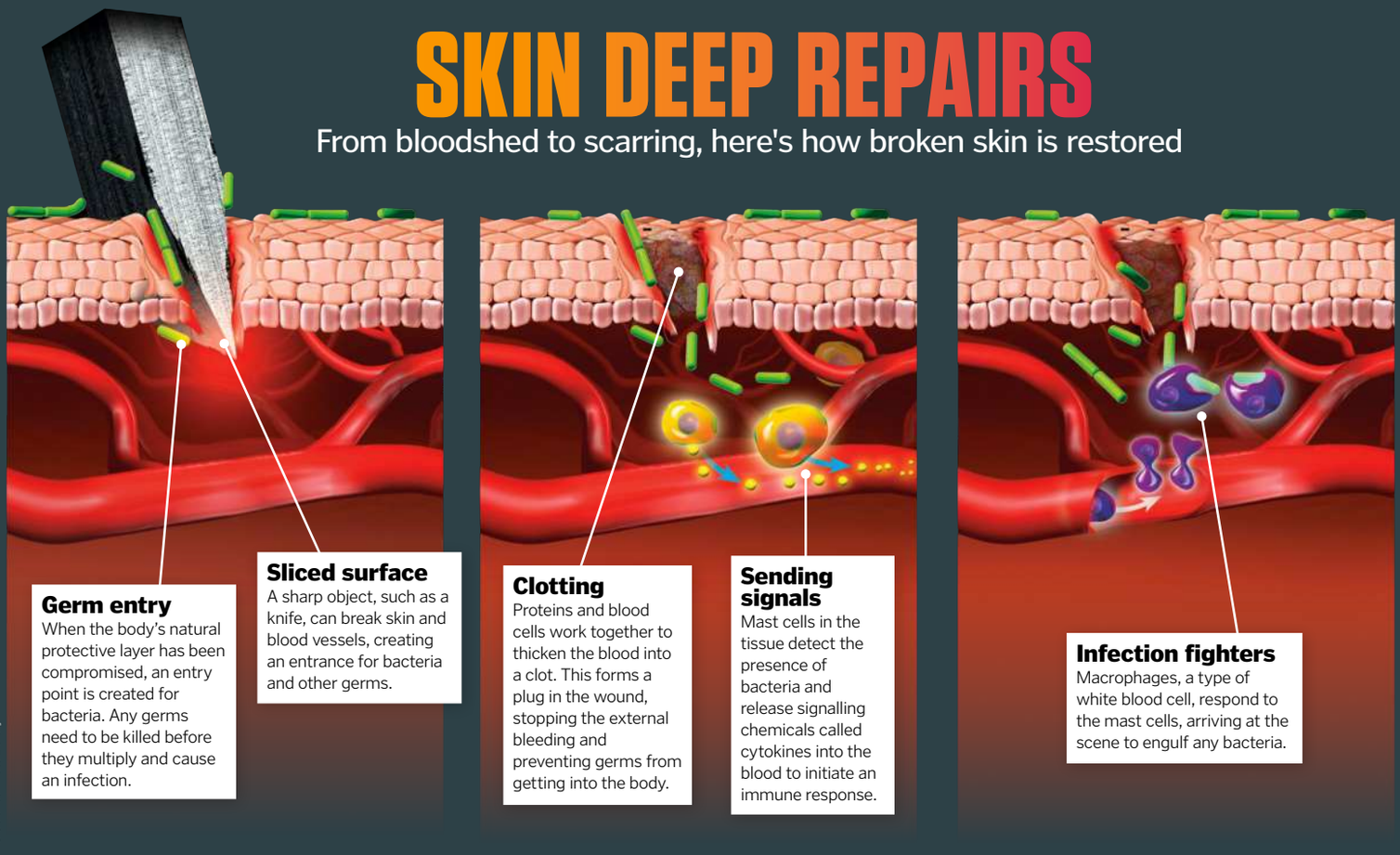
What do we do if a sharp object tears our skin, exposing the flesh and blood that lies beneath our outer protective layers? Thankfully, just as different parts of our bodies are specialised in their unique roles, they have also evolved methods to piece organs back together and restore health from significant sickness. With the constant influx of germs and the quick deterioration that comes with increasing blood loss, we wouldn't last very long without our incredible ability to heal.

When you look in the mirror each day, you may think that the image you are greeted with is fairly constant. But if you were to look at yourself in 28 days time, you would be wearing a completely new skin. The cells that make up your skin are constantly changing – an essential process needed for repairing damage and protecting you. Skin is the largest organ you own. Covering your entire body, it is very exposed to your surroundings, making it the most commonly damaged part of the body. Being able to create new, strengthened skin cells enables your body to close gaps made in this shield, limiting the amount of healing and infection fighting that needs to take place in more vulnerable organs of the body.

Even biological functions that we once thought were fixed have been shown to change. Neuroplasticity is a phenomenon that alters neural signals in the brain. By training the brain, some people have been able to create new pathways, enabling them to improve their memory and even recover from brain damage. As we find new ways to manipulate the most complex areas of human biology, we are expanding the means of reversing damage.

SKIN DEEP REPAIRS

From bloodshed to scarring, here's how broken skin is restored



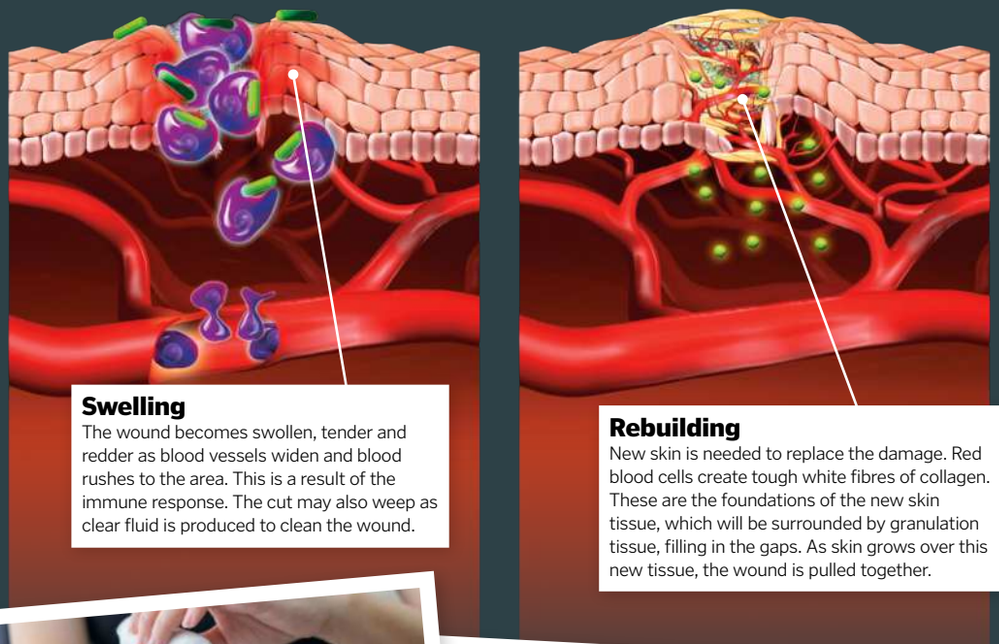
Germ entry
When the body's natural protective layer has been compromised, an entry point is created for bacteria. Any germs need to be killed before they multiply and cause an infection.

Sliced surface
A sharp object, such as a knife, can break skin and blood vessels, creating an entrance for bacteria and other germs.

Clotting
Proteins and blood cells work together to thicken the blood into a clot. This forms a plug in the wound, stopping the external bleeding and preventing germs from getting into the body.

Sending signals
Mast cells in the tissue detect the presence of bacteria and release signalling chemicals called cytokines into the blood to initiate an immune response.

Infection fighters
Macrophages, a type of white blood cell, respond to the mast cells, arriving at the scene to engulf any bacteria.



Swelling
The wound becomes swollen, tender and redder as blood vessels widen and blood rushes to the area. This is a result of the immune response. The cut may also weep as clear fluid is produced to clean the wound.

Rebuilding
New skin is needed to replace the damage. Red blood cells create tough white fibres of collagen. These are the foundations of the new skin tissue, which will be surrounded by granulation tissue, filling in the gaps. As skin grows over this new tissue, the wound is pulled together.

Bandages can help keep a wound clean

Bones aren't as quick to heal as our skin

Medical intervention

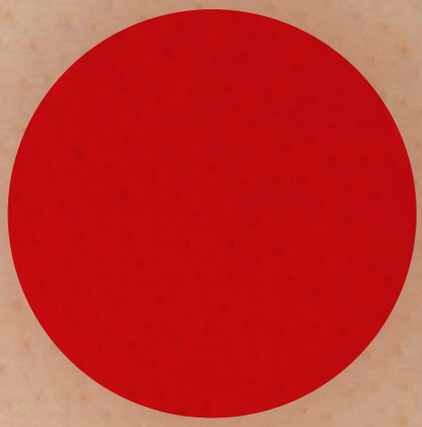
Although the body has an effective system in place for banishing infection and repairing the skin, sometimes medical assistance is needed for the safest healing process. If a cut is deep, or has an object embedded in the tissue, it is best to go to hospital for more urgent treatment. Signs that you will need stitches include bleeding that persists for over ten minutes of applying pressure or if the cut looks particularly deep. Stitches are loops of thread used to hold skin together so that there is less of a gap to fill during the healing process. This makes the healing process speedier, minimising the chance of infection and scarring. Once the skin has healed, hospital staff can remove the thread.

A knot holds stitches in place until they are ready to be removed

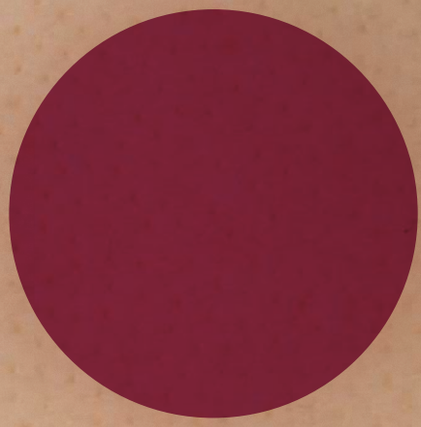
THE BRUISE SPECTRUM

What can the colour of your bruise tell you about its healing stage?

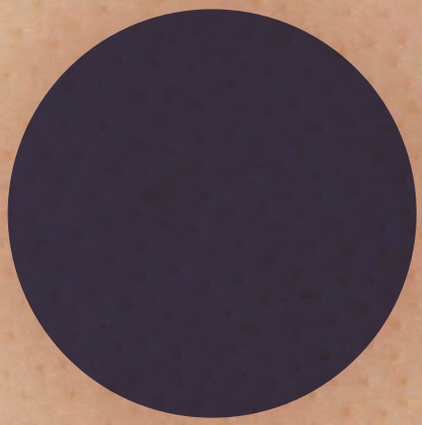
As bruises form and fade, they generally follow a colour pattern. By understanding why these changes occur, you can predict the age of a bruise on your body. The colour of your skin will also change their appearance. Generally, lighter skin tones will display more redness and visible yellow colours, while reddening in darker skin may be less noticeable.



1 Initial colouring
Occurring quite soon after an impact, newly leaked blood is bright red in colour, causing red tones to show through the skin.

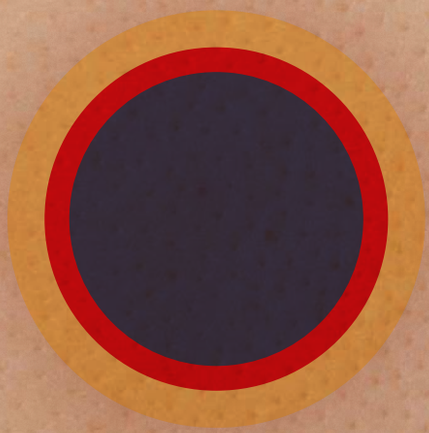


2 Losing oxygen
After a few hours, oxygen levels in the leaked blood start to decrease, as it has left the circulatory system. This causes the bruise to darken in shade.

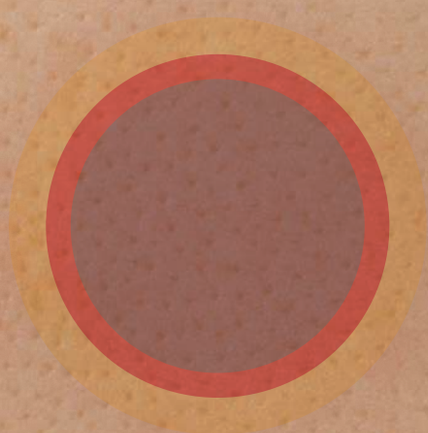


3 Oxygen depleted
A day later, the blood has lost all its oxygen. The red cells begin to break down, and iron is released, turning the bruise darker blue, purple or black.

4 Healing begins
Shades of green indicate the first stages of healing. The green is caused by the pigment biliverdin, which is produced as haemoglobin is broken down.



5 Final colouring
The biliverdin is converted into bilirubin. During this process, the green edges become more yellow.



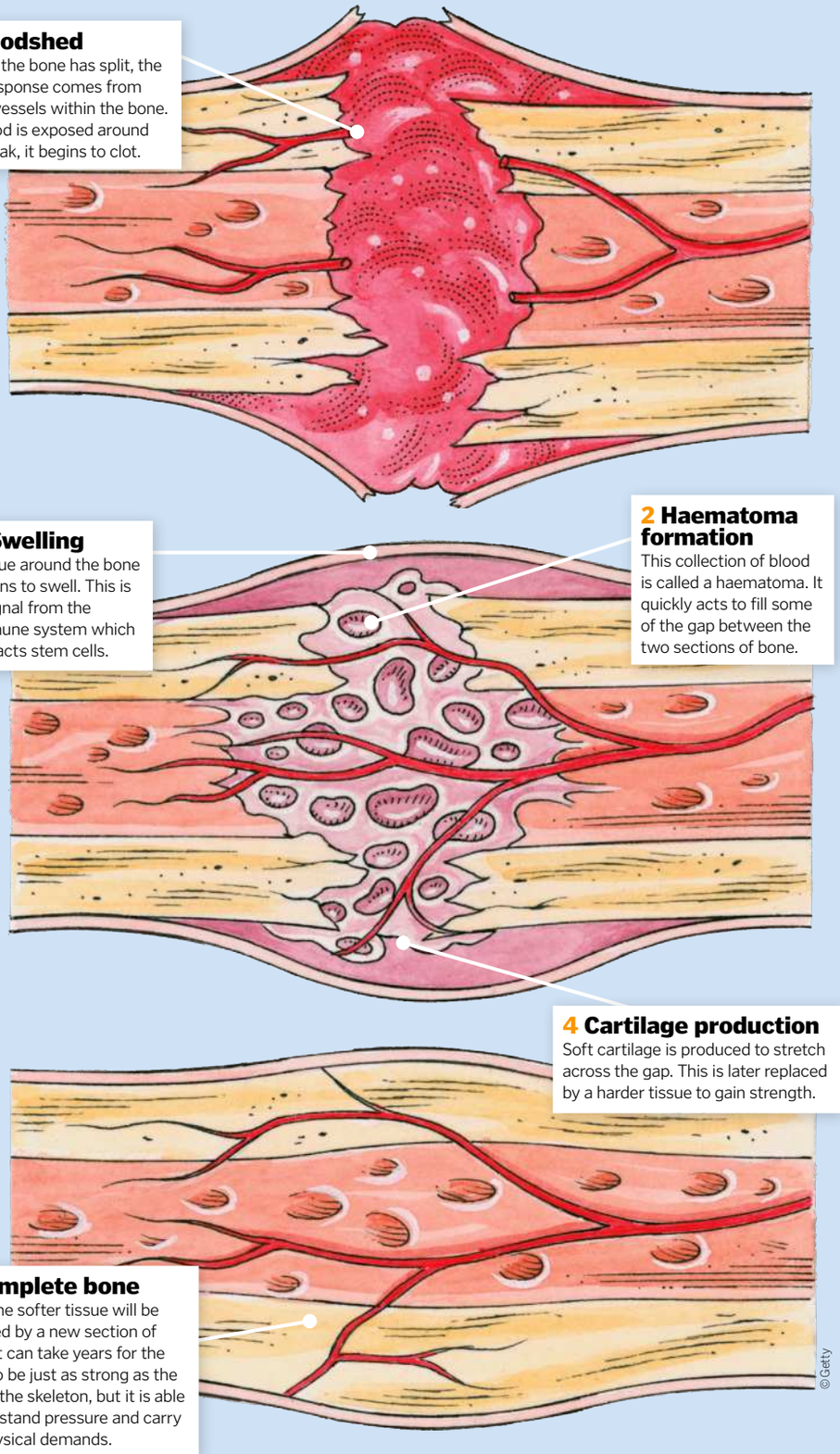
6 Fading
Finally the bruise will begin to fade, becoming brown and lighter as it does so. Most will disappear within two weeks.

Battered and bruised

Blood spills don't necessarily have to be messy. If you class yourself as a clumsy person, the presence of these ever-changing patches on your skin will be a common occurrence. Bruises appear on the skin when the small blood vessels that lie underneath it break. As the blood spreads into the soft tissue, a mixture of blue, purple, red and brown colours can present themselves. Bruises are extremely common; they can be a reminder of that time you missed the gap and fell victim to the corner of a table, or the day you slipped on the rocks.

However, some people are more likely to bruise than others, based on the thickness of their skin and the strength of the underlying tissue. If a bruise doesn't disappear after two weeks, or you don't know why you are bruising, it is best to get them checked out by a doctor.

Cooling the area with an ice pack can help to reduce bleeding beneath the skin



1 Bloodshed
Where the bone has split, the first response comes from blood vessels within the bone. As blood is exposed around the break, it begins to clot.

2 Haematoma formation
This collection of blood is called a haematoma. It quickly acts to fill some of the gap between the two sections of bone.

3 Swelling
Tissue around the bone begins to swell. This is a signal from the immune system which attracts stem cells.

4 Cartilage production
Soft cartilage is produced to stretch across the gap. This is later replaced by a harder tissue to gain strength.

5 Complete bone
Soon the softer tissue will be replaced by a new section of bone. It can take years for the bone to be just as strong as the rest of the skeleton, but it is able to withstand pressure and carry out physical demands.

An X-ray can show where the fractures in bones are

REPAIRING BONES

How does the skeleton fuse together beneath a cast?

Your bones create a framework to give your body structure. They support you when you move and are designed with the strength to protect our most vulnerable organs. However, not even your bones are invincible, and this becomes all too apparent when you hear a telltale 'crack' after a hard fall.

Broken bones are a relatively common occurrence, and after the early pain, the healing process can seem miraculously straightforward. You might have to get used to having an arm in a sling for a few weeks, or a leg covered in an inflexible concrete-like cast, but once these are removed your bones can return to their roles feeling as good as new.

An essential part of this is positioning. When bones are in the right place, your body is quick to recreate your skeleton's form, but without medical staff to wrap up your limbs and position the pieces, you could end up with your bones reattaching improperly and at the wrong angles. This can make the use of a limb or body part more challenging, and even painful.

Why teeth don't heal

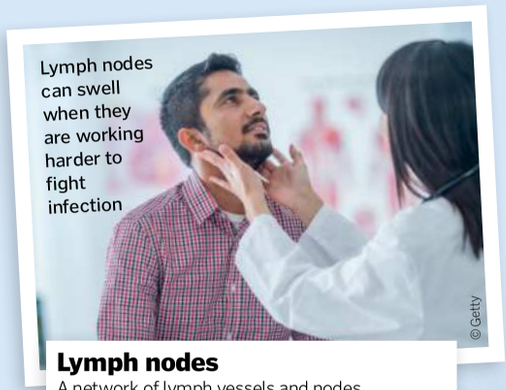
Teeth give you two chances to look after them. As a child it doesn't matter so much if you chip a tooth or knock them out. You have a backup set waiting to grow in. Unlike your skin and bones though, these eating tools aren't the best of your body's healers. The enamel covering each tooth is unable to self-repair and is designed to last for the remainder of your life. In order to keep their strong properties, they have hardly any cells or proteins that can promote healing. Instead, 90 per cent of tooth enamel is made of minerals. While dentin – the layer beneath our enamel – is alive and can heal itself, the white outer crown has no living cells and is vulnerable.

Artificial teeth can be made to replace damaged adult teeth

OVERCOMING INFECTION

Our bodies constantly monitor themselves and are prepared for a fight against invaders

Beyond the closing cuts we can see and the hospital scans that show deeper injuries, our entire bodies are constantly working to remove hidden dangers we may not even be aware of. Whether they're filtering the contents of our bodies before we suffer any symptoms or battling a backlog of microorganisms while we rest, these are the internal instruments that defend and repair us.



Lymph nodes can swell when they are working harder to fight infection

© Getty

Lymph nodes

A network of lymph vessels and nodes throughout our bodies works as a filtering system to remove toxins in the body's tissues. It flushes out any viruses, bacteria or waste material to reduce the chance of infection. You have hundreds of lymph nodes, constantly receiving contaminated fluid. Equipped with immune cells to fight the invaders, lymph nodes destroy germs carried in through the lymph fluid.

Thymus gland

Unlike most vital body parts, this gland slowly gets smaller, and is replaced with fat as you age. Before it shrinks, it needs to produce all its life-saving cells before you reach puberty. The cells it makes are T-cells. These help to build an immune response to viral infections by targeting and remembering foreign substances. The thymus gland is also responsible for screening the T-cells produced, killing any that are likely to attack healthy cells. The body's ability to produce an immune response means that when a known infection returns, it can be beaten more quickly.

5 FACTS ABOUT HELPING YOUR BODY TO HEAL

1 Add nutrients to your diet
Protein is an essential macronutrient used to repair tissue, vitamin C helps the body produce collagen, carbohydrates provide energy for white blood cells and vitamin A controls inflammation.

2 Get more sleep
While you are sleeping there are fewer demands made on your heart, and hormones are produced to relax the body and control inflammation. Less energy is being used up by other parts of your body, such as muscles, and more white blood cells are produced as you sleep.

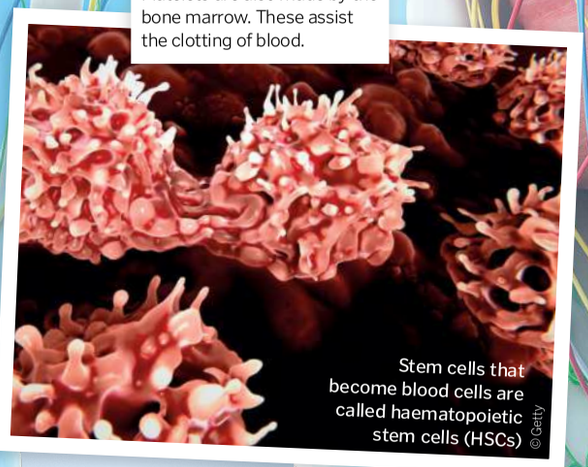
3 Keep your blood pumping
Regular exercise can help wounds to heal quicker, but be careful not to drain your energy. Keeping moving helps increase the amount of oxygen that reaches damaged areas as it is transported in your blood. Oxygen is needed by cells as they kill infections, as well as assisting the growth of new tissue.

4 Stay clean
Wounds that become infected take longer to heal because your body is working to get rid of the infection before it can restore the tissue. Clean injured skin with antiseptic solution regularly to make the healing process quicker and easier.

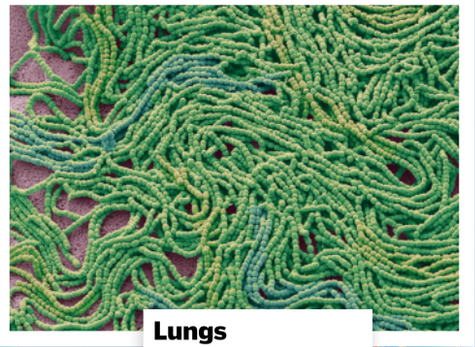
5 Don't pick your scabs
Scabs form a layer of protection while the cut heals. They can feel itchy and uncomfortable, but it's important not to touch or pick at them. Picking your scabs increases the risk of infection and slows the healing process. It will also increase the chance of scarring.

Bone marrow

This spongy substance found at the centre of our bones plays a crucial role in healing both wounds and infection. Constantly producing stem cells, these eventually differentiate to become vital blood cells. Each of the three blood cells made in the bone marrow carries a valuable job for restoring health. The white blood cells patrol the body to fight infections, while red blood cells carry oxygen in the blood, bringing this essential component to the most vulnerable areas. Platelets are also made by the bone marrow. These assist the clotting of blood.



Stem cells that become blood cells are called haematopoietic stem cells (HSCs)



This scanning electron micrograph shows a close up of mucus that has been produced in the airways

Lungs

One easy access point for health-threatening invaders is through the air that we breathe. We need to let the surrounding air in through our lungs in order to provide our bodies with oxygen. But alongside the oxygen there can be germs lingering. Just as your nose does when detecting infectious foreign bodies, the surface of the lungs produces mucus. Tiny hairs in your airways will then sweep the mucus and unwanted germs out of your lungs. If this builds up you may notice that you develop a cough. This assists the movement of the mucus.

Spleen

This fist-sized organ is found on the left side of your body, near your stomach. Working as your blood's quality control base, it analyses the blood passing through it and makes necessary changes. As blood is pumped through its narrow vessels, it removes any damaged or old red blood cells, breaks them down and returns their material to the bone marrow.

DID YOU KNOW? *The liver is the only organ in the body that is able to regenerate, fully repairing itself in 30 days*

WHEN FOOD GOES BAD

WHAT'S EATING AWAY AT THE EDIBLES IN YOUR KITCHEN?

Words by **Ailsa Harvey**

Our lives revolve around food. As we fill up our cupboards with our weekly shopping and consume the shelves' contents multiple times a day, our favourite snacks only have a fleeting stay in our homes. Food is a permanent necessity, sustaining our health throughout our lives. But the shelf life of each item is remarkably temporary, giving our kitchens a high turnover rate.

On many airtight jars, it's suggested that you consume the entire contents within one week of opening it, and the freshest foods, such as fruits and vegetables, will remain so for an even shorter time period. The ingredients for our meals come with unique countdown clocks, and the timing for peak condition can sometimes be unpredictable. In order to fully understand the quality of each perishable food, you need to know the science behind their demise.

Food begins to rot when its cells die and break apart. The proteins inside leak out of these gaps and begin to eat away at the cells. Working from damaged ones to the healthier cells surrounding them, soon the entire piece of food will start to disintegrate. As bacteria and fungi join the feast and increase in numbers, their combined waste products add foul tastes and smells to the previously fresh food. Changes in appearance, odour and texture are all signs of decay.

Food spoilage is inevitable, but there are some ways you can slow this process down. Effective methods to prolong quality are used in food factories, as well as by consumers at home. Removing oxygen from packaging and sealing food until use stops air and microorganisms from compromising a food's freshness. Factories also heat treat many of their consumable products, as the majority of microorganisms can't withstand high temperatures.

WHAT CAUSES SPOILAGE?

FROM CREATURES TO CLIMATE, THESE ARE THE CULPRITS IN FOOD'S EXPIRATION


© Alamy

MICROORGANISMS

When bacteria and fungi grow in food, they can cause a change in colour, texture and smell. Many foods are not just desirable to us humans, but can also provide energy to these single-celled organisms. The microbial world is a diverse one. Some food growths create a green, mouldy appearance, clearly indicating the presence of fungi, while others can grow to harmful levels with zero visibility. It's important to remember that not all microbes are bad to consume, and some even hold health benefits.


© Alamy

AIR

21 per cent of air consists of oxygen, which can attack the fats in food. In fact, oxidation is the main cause of spoilage in fatty foods. When the fat oxidises, it forms smaller short-chain carbon compounds. It's these compounds which produce a strong smell and unappealing taste.

ENZYMES

Enzymes are proteins that speed up some of foods' chemical reactions, and one of their purposes is to ripen fruits and vegetables. Enzymes don't just work to make food perfect for your palate, though, and they will continue to turn fruit from unripe, to ripe, to over-ripe. They are the reason your fruit continues to the disgustingly soft, squishy stage. When you bite into fruit, oxygen reaches the broken plant tissue. In apples, enzymes work quickly with this oxygen to produce compounds with a brown colour.


© Getty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LIGHT

Food and drink are often covered in light-proof packaging to prevent photodegradation, the alteration of products due to light exposure. Some reactions that occur within foods require light for them to take place. Light can cause damage to the chlorophyll of fruit and vegetables. These are the cells that give some plants their colour. Over time this reaction can cause discolouration in foods.

ANIMALS

Although we have designated some items as 'human food', they are not exclusively sought after by us. Other animals share the same tastes, and so in order to keep some fresh for ourselves, we need to store food away from animals like rodents, insects and parasites. When food is damaged by these creatures, it makes the deterioration process quicker, as well as increasing the likelihood of spreading disease.


© Getty

TEMPERATURE

Different foods have their own optimum temperature for storage, which will prolong their shelf life. Usually warm temperatures are avoided during storage, as this can speed up the rate of enzyme activity, while freezing temperatures can cause some foods to break, like the protective shell surrounding eggs. Microorganisms usually thrive at room temperature, making fridge or freezer storage the best option for fresh foods. Between 10 and 37 degrees Celsius is the most common range in which food is handled. Just a ten degree increase in temperature can double the rate of chemical reactions within a food item.


© Getty

PHYSICAL DAMAGE

When bringing shopping into the house, you might take extra care with the softer fruits and food unprotected by packaging. Some fruits and vegetables have their own protective layer, but when this is damaged, threats such as microorganisms, air and small creatures can get into the food, increasing the rate of spoilage.


© Getty

MEET THE MICROBES

HOW DO THESE CELLS FORM COLONIES, CONTAMINATING OUR FOOD?

Mould

Foods that contain moisture are prime targets for mould. Growing from spores, which are carried in the air around us, these thread-like fungal structures can become harmful when they are ingested. Coming into contact with food, they use the food's nutrients to multiply, spreading over the surface and throughout the food. When enough mould has accumulated, it can usually be observed in furry or dusty-looking patches of white, or shades of green.

Mould's ability to withstand high concentrations of sugar and salt means that it can thrive on foods that bacteria and yeast can't. This is why it is commonly found living in jams, which bacteria struggle to survive in, and often feeds on the sugar in bread, fruit and vegetables. Foods with a high water content are also prime targets, but processed foods can usually fight off mould due to the high levels of preservatives added to them.

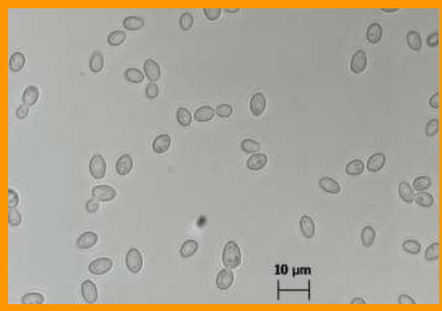
© Getty

The grey mould found on strawberries is caused by the fungus *Botrytis cinerea*

Out-of-control yeast

These single-celled fungi are often purposefully added to food. Feeding on sugars, the cells release carbon dioxide, which is beneficial for the baking of dough, as it makes it rise. Although a little yeast in food is good for you, when uncontrolled growths of yeast enter the body, it can cause infection.

Different strains of yeast can tolerate different acidities in food, but yeasts are typically the most prevalent microbe for spoiling carbonated products such as fizzy drinks. This is due to their ability to survive in environments of very low pH and high carbonation. By producing ethanol as a waste product, spoilage yeasts can drastically change the taste of drinks it contaminates. It can also eat away at preservatives, which further reduces the shelf life of food and drink.

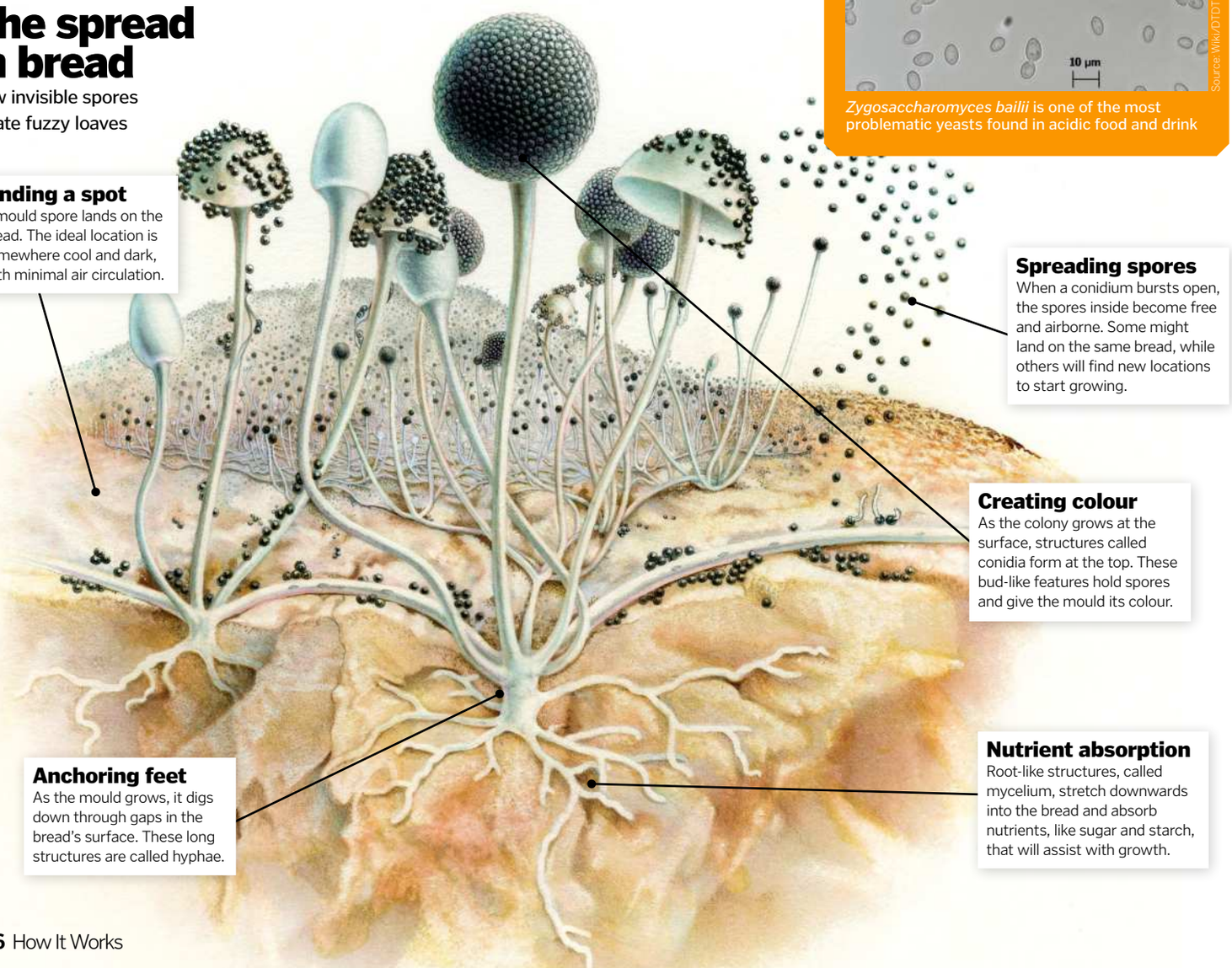


Source: Wiki/DTDT

Zygosaccharomyces bailii is one of the most problematic yeasts found in acidic food and drink

The spread in bread

How invisible spores create fuzzy loaves



Finding a spot

A mould spore lands on the bread. The ideal location is somewhere cool and dark, with minimal air circulation.

Spreading spores

When a conidium bursts open, the spores inside become free and airborne. Some might land on the same bread, while others will find new locations to start growing.

Creating colour

As the colony grows at the surface, structures called conidia form at the top. These bud-like features hold spores and give the mould its colour.

Anchoring feet

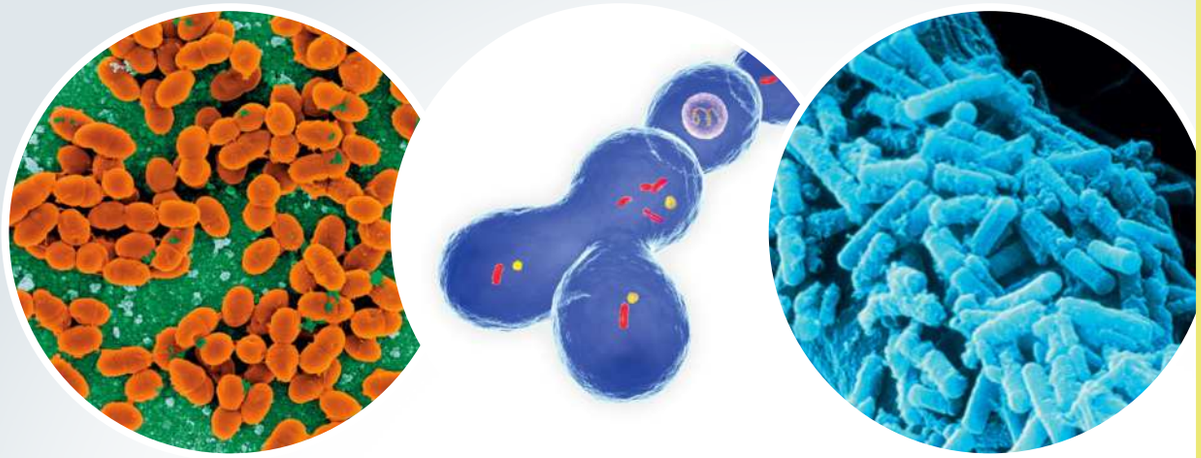
As the mould grows, it digs down through gaps in the bread's surface. These long structures are called hyphae.

Nutrient absorption

Root-like structures, called mycelium, stretch downwards into the bread and absorb nutrients, like sugar and starch, that will assist with growth.

HEAT-RESISTANT BACTERIA

THESE THREE BACTERIAL GROUPS CAN LIVE ON FOOD IN A RANGE OF TEMPERATURES



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Psychrotrophs

LACTOCOCCUS PISCIUM

Psychrotrophic bacteria are those that can grow in low temperatures. Some species have been known to survive at zero degrees Celsius or lower, but most have an optimum growing temperature between 10 and 20 degrees Celsius.

Multiplying at low temperatures is a cause for concern when it comes to food, as the cooler climate of the refrigerator will not work in preventing these microbes from growing. *L. piscium* is one of the most common of all food-spoiling bacteria found in fridge-stored products. It mainly targets meat, giving it a sour smell.

Mesophiles

LEUCONOSTOC CITREUM

These bacteria thrive in much more moderate temperatures, between 25 and 35 degrees Celsius. Keeping food products in the fridge is a great way to keep them fresher for longer, preventing these bacteria from growing. Meat often has naturally occurring bacteria, and so keeping it cool before cooking stops this bacteria multiplying.

L. citreum is a specific mesophile, called a lactic bacterium. This means that it can live without needing any oxygen, and is a threat to food items like cooked ham, which is kept in vacuum-packed packaging for freshness.

Thermophiles

GEOBACILLUS STEAROTHERMOPHILUS

Heating food over a flame is a key way to kill lurking microbes, but not all microbes are heat-haters. Thermophilic bacteria actually benefit from this heat, living in temperatures above 45 degrees Celsius. *G. stearothermophilus* is one thermophilic species, causing problems largely within the dairy industry. Being immune to the heat treatment of milk, it causes much of the spoilage in non-refrigerated dairy products. The bacteria doesn't hold significant health risks, but causes unwanted fermentation and souring in many heat-treated food products.

Best before vs use by

Spoiled foods are not always visibly apparent, and so many of us rely on the expiry dates that have been printed on their packets. But why do some packets say 'best before', while others give a 'use by' date? It's important to know the difference between these two, because while one is there to prevent you from encountering an unpleasant taste, the other is printed for your health.

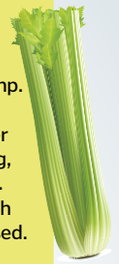
Food that has passed its best-before date can still be safe to consume, but isn't in its peak condition. Use-by dates are chosen for food that goes off quickly, such as meats and fish. You can eat the food up until the date printed, but when this date passes, you should throw it away. You shouldn't eat food or drink with an expired use-by date, even if it looks and smells normal, as it could make you ill.

© Getty

About 30 per cent of the 'expired' food we throw away had a 'best before' date and could still been eaten

SIX TRICKS TO STOP FOOD GOING BAD

1 Berry bath
Wash your berries in a diluted vinegar bath before rinsing, drying them on paper towels and storing in the fridge. This can kill any lingering bacteria and mould spores and extend their shelf life.



2 Crisp celery wrap
Keeping celery in its loose plastic bag can cause it to go limp. This is due to the release of the ripening hormone ethylene. Over time this gets trapped in the bag, building up to become over-ripe. Wrap celery in foil instead, which allows the hormone to be released.

3 Tomatoes out the fridge
Tomatoes that are kept in the fridge can lose their flavour and become slightly too soft in texture. For the freshest, most flavoursome tomatoes, keep them in the cupboard.

4 Onion and potato enemies
You should store your potatoes away from onions if you want to keep them for a while. Next to each other, the ethylene gas released by onions will cause potatoes to sprout prematurely.

5 Plastic-free mushrooms
When mushrooms go bad, the water they release encourages bacterial and fungal growth, producing a slimy covering on their surface. If you remove the container they're sold in and wrap them in paper, this can absorb some of the excess moisture.

6 Separate bananas
Being connected in a bunch makes bananas ripen at the same time. As you are unlikely to eat the whole bunch at the same time, separating them helps to avoid them all going brown together.

6x © Getty

ALL ABOUT YOUR DNA

UNLOCKING THE SECRETS OF OUR GENETIC CODE WILL MAKE US MASTERS OF OUR OWN BIOLOGY

Words by **Laura Mears**

DNA is one of the greatest inventions of the natural world. It's a chemical library, capable of storing vast quantities of data for billions of years. Passed from one generation to the next, this microscopic structure is the engine of evolution. Every living creature uses DNA as its instruction manual. The genes contained within it tell cells how to make the proteins they need to survive, grow and reproduce.

DNA also records history, tracing the path evolution has taken to create the plants and animals we see today. Unlocking the secrets of DNA not only allows us to read our own life story, it also gives us the ability to predict – and even change – the future.

DNA is a treasure trove of information that we're only just beginning to explore. Scientists didn't even know it existed until the late 1800s, and it wasn't until the 1950s that they really started to understand how it worked. In the 1970s, scientists finally developed a technique that allowed them to read the letters of the genetic code. Suddenly it was possible to look inside our own instruction manual and see how humans are made.

> *"DNA is a treasure trove of information that we're only just beginning to explore"*

It took over ten years to complete the first map of the human genome, and the results that came out of it were a huge surprise. Scientists had predicted that it would take as many as 100,000 genes to build and maintain a human body. But the Human Genome Project revealed that we have less than a quarter of that number. Even rice plants have more genes than we do.

Today's gene sequencing technology is so advanced that machines can read off an entire human genome in a matter of hours. There are millions of individual sequences now on public record, allowing researchers to investigate the tiny genetic differences that make us who we are. These differences are the key to understanding everything from our family history and our physical features to our risk of developing diseases.

At the moment our understanding of DNA is still in its infancy, but we are standing on the precipice of a genetic revolution. Tracing our biology back to the level of our DNA will one day make it possible to customise our genetic code and even cure genetic diseases. But before we reach that point, we need to work out what every letter of that code is for.

The link between some genes and the traits they control is simple and clear, but for most the relationship is complex. With so few genes in the human genome, it is inevitable that many have more than one role to play in building a body. Genes work together in complex and interconnected networks to shape the people that we become.

To complicate matters further, genes make up only around one or two per cent of the human genome. The rest of our genetic code controls how, when and why we use our genes. How that works is mostly a mystery. Understanding gene networks – and learning to edit them – is the next step on the path to becoming masters of our own biology.

What is DNA?

DNA is the most famous molecule in the world, but what goes on inside that double helix? At the heart of it are four chemicals called nucleotides. Each contains a pentagon-shaped sugar molecule, a structure called a phosphate group and a protein fragment called a base.

The sugar and the phosphate group are the same for every nucleotide. They join together side by side to form the backbone of each DNA strand. Like LEGO bricks, they only connect one way round; the phosphate of one nucleotide slots into the sugar of the next. This means that DNA strands have a definite 'up' and 'down'. The top is called the five prime (5') end, and the bottom the three prime (3') end.

The two strands of a DNA helix face in opposite directions, one running five prime to three prime, and the other three prime to five prime. They twist together in a right-handed helix. If you look closely you'll notice that the alternating twists are uneven: one big (the major groove) and one small (the minor groove).

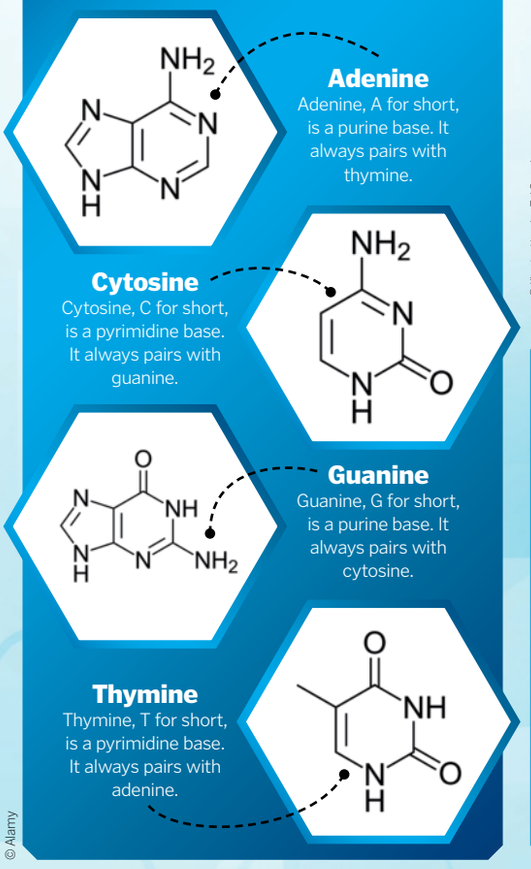
The bases connect the two DNA strands together like the rungs of a ladder. They form pairs, known as base pairs, linked by strong interactions called hydrogen bonds. There are four bases – adenine (A), cytosine (C), guanine (G) and thymine (T) – and they are extremely picky about the bonds they will form. Adenine will only pair with thymine, and guanine will only pair with cytosine. This means that if one strand carries the sequence ATGC, the other has to have the sequence TACG.

This strictness allows a cell to easily make copies of its genetic code. It simply unzips the two strands and uses them both as templates to assemble two new strands, copying the matching nucleotides into the empty slots.

The most important role for DNA is to carry information from one generation to the next. This information is written in code, using the

Four vital molecules

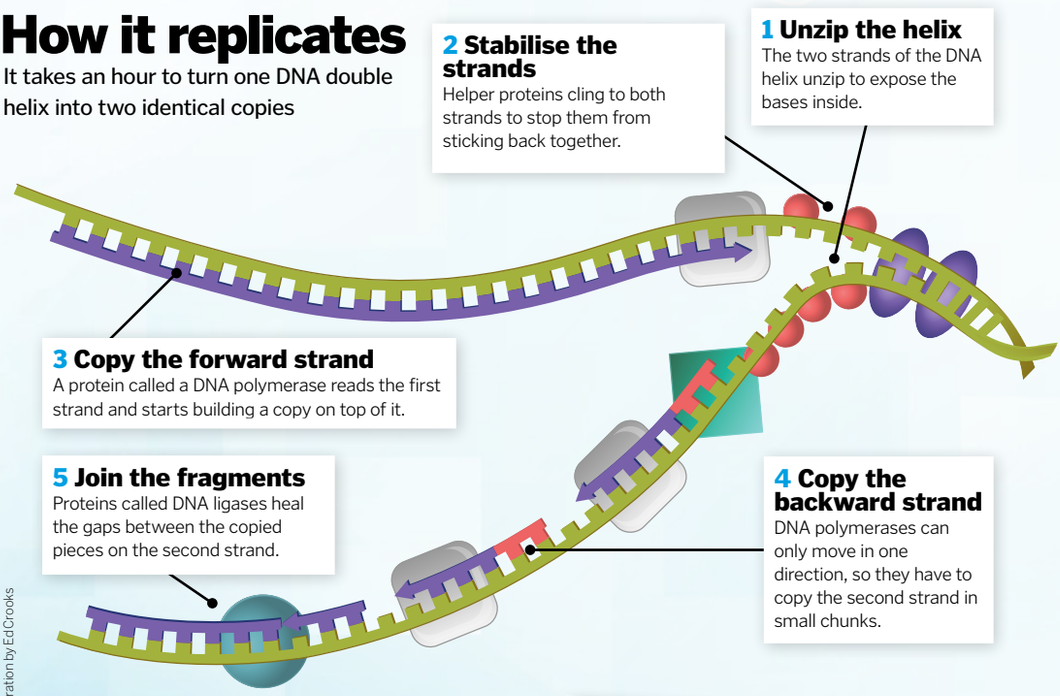
DNA's organic bases make up the most important code in the universe



© Alamy

How it replicates

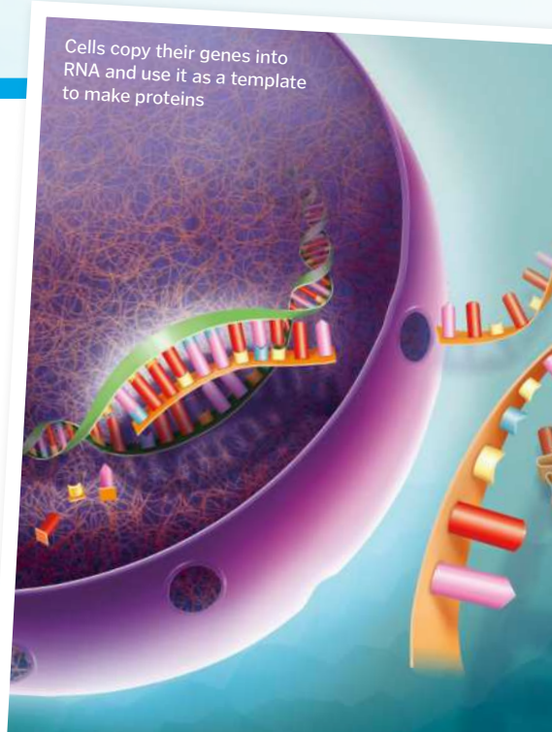
It takes an hour to turn one DNA double helix into two identical copies



© Illustration by Ed Crooks

WHAT IS RNA?

DNA is not the only genetic molecule in nature; organisms also make strands of genetic material called RNA. Chemically the two molecules are quite similar, but they have very different roles to play. DNA forms stable double strands that carry the entire genome safely from one generation to the next. RNA forms unstable single strands that carry smaller amounts of genetic data for shorter amounts of time. Cells use RNA to make temporary copies of their genes. These copies act as templates for the molecular machines that make proteins. The machines read through the code three bases at a time, adding the corresponding amino acid to a growing protein string.



Twisted structure

How does two metres of DNA fit into a cell smaller than a grain of sand?

8 Chromosomes
Humans have 46 chromosomes: 23 inherited from the mother and 23 from the father.

7 Nucleus
The chromosomes are found in the centre of the cell, protected by two layers of membrane.

6 Chromosome
Each strand of chromatin forms a structure called a chromosome.

5 Chromatin
DNA, together with histones, forms a compressed substance called chromatin.

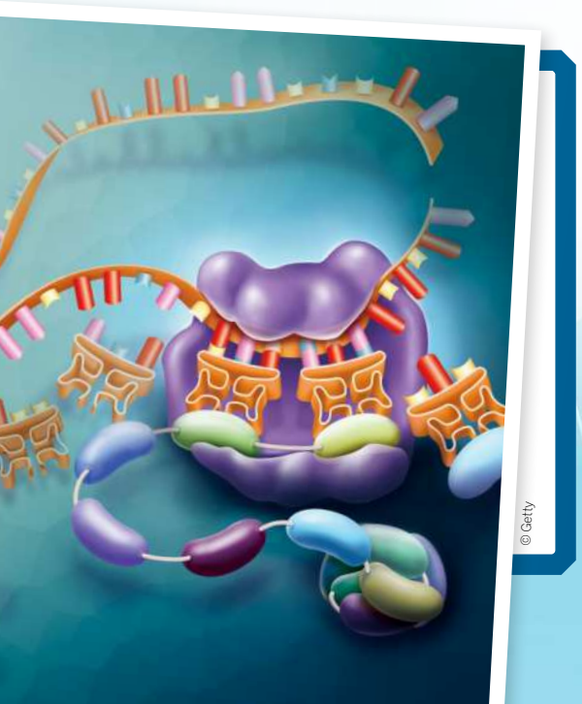
4 Histones
These bead-shaped proteins wind the DNA into neat fibres.

1 Bases
The four bases carry the genetic code and link the two strands of DNA together.

2 Double helix
DNA has two strands, twisted together to form a distinctive spiral.

3 Backbone
Alternating sugar and phosphate molecules make up the outer ribbon of the DNA helix.

> *"Genes are the parts of DNA that carry the instructions for making proteins"*



four bases as chemical letters. Scientists have yet to decode the meaning of the entire human genome, but they have cracked the code that makes up our genes.

Genes are the parts of DNA that carry the instructions for making proteins: the molecules that build our bodies and do the hard biochemical work that keeps us alive.

The building blocks of proteins are amino acids, and there are 20 different types of amino acid to choose from. The order of amino acids in a protein dictates how the protein folds up to form a 3D structure and how it behaves inside the body.

The instructions for building proteins are written into our genes as strings of three-letter words called codons. It is possible to make 64 three-letter words using the four DNA bases. This means that, just like in English, some genetic words have the same meaning.

The codon ATG means 'start', signalling that the instructions to build a protein begin here. The codons TAA, TAG and TGA mean 'stop', signalling that the protein ends here. The rest correspond to different amino acids. Cells copy the genes they want to use and read through the codons one by one, selecting the matching amino acid and connecting it to a growing string. When they reach a stop codon, they know that the string is complete, and the protein is ready to fold into its 3D shape.

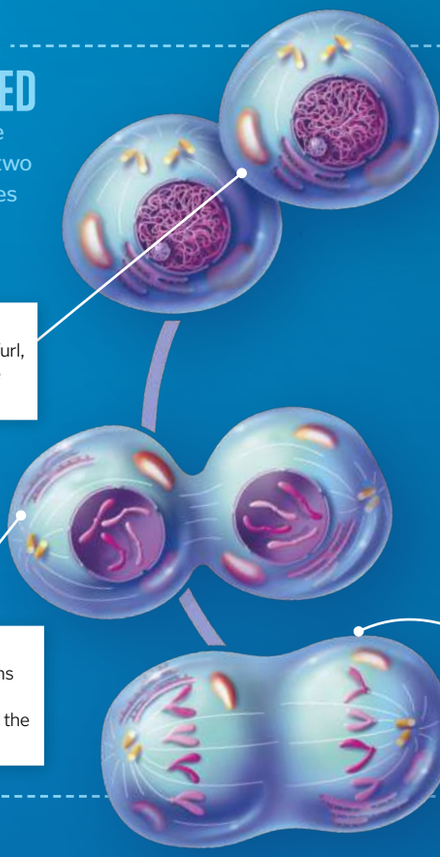
History of DNA

HOW WE'VE COME TO UNDERSTAND MORE ABOUT IT SINCE ITS DISCOVERY


© Alamy

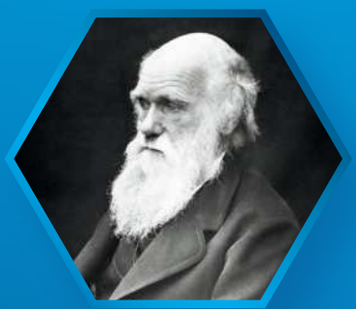
MITOSIS EXPLAINED

How does one cell split into two identical copies of itself?



5 Interphase
The chromosomes unfurl, allowing the cell to use and copy its genes.

4 Telophase
A new nucleus forms around each set of chromosomes, and the cell splits in two.


Source: Wiki/Leonard Darwin

1859

Charles Darwin publishes *On the Origin of Species*, describing how life evolves through natural selection.

1879

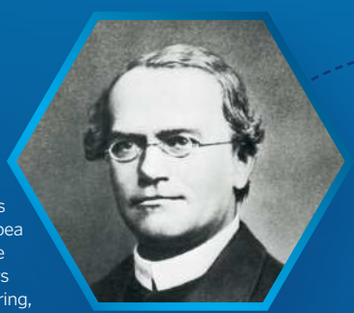
WALTHER FLEMMING
Flemming becomes the first person to observe cell division, or 'mitosis'. He dyes salamander DNA with a chemical called aniline. He then watches as the chromosomes in the nuclei turn into thick threads, which line up across the middle of the cell. The threads then separate into two groups, and the cell splits in half.

> *"They base their breakthrough on the work of dozens of other scientists"*

1800 1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910

1865

GREGOR MENDEL
Mendel, a monk, presents his work on dominant and recessive genes after performing experiments on nearly 30,000 pea plants. He cross-pollinates pea plants to find out how traits like colour and texture pass from one generation to the next. He discovers that some traits always pass from parent to offspring, while others sometimes seem to skip a generation.


Source: Wiki/Unknown Author


Source: Wiki/TBD

1869

FRIEDRICH MIESCHER
Miescher finds a strange substance while examining the pus inside used bandages. Pus contains white blood cells, and inside their nuclei, Miescher discovers a chemical that contains phosphorous and nitrogen. He names it 'nuclein'. The substance is part protein, part acid, so scientists later rename it 'nucleic acid'.

MENDEL'S PEAS

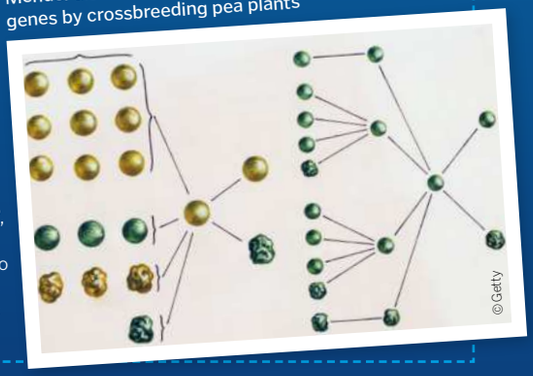
PARENT GENERATION
Mendel starts his experiment with two pure-bred peas: a smooth variety and a wrinkly variety. The gene that determines texture has two variants, known as 'alleles'.

F1 GENERATION
When Mendel crosses the pea plants, they inherit one allele from each parent: a smooth allele and a wrinkly allele. The smooth allele is 'dominant', so all the peas are smooth.

F2 GENERATION
When Mendel crosses these plants, 25 per cent inherit two smooth alleles, 25 per cent inherit two wrinkly alleles and the rest inherit one of each.

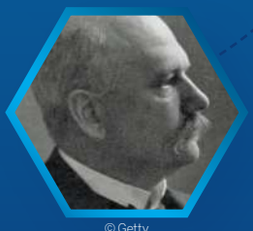
RECESSIVE GENES
The wrinkly allele is 'recessive', which means that the peas have to have two copies of it to end up with wrinkly skin. Peas with one smooth allele always end up smooth.

Mendel discovered dominant and recessive genes by crossbreeding pea plants


© Getty

1910

ALBRECHT KOSSEL
Kossel receives a Nobel Prize for discovering nucleic acids. He works together with his students to analyse the chemical components of nuclein, discovered by Miescher. They find that this strange chemical contains five types of nucleic acid: adenine, cytosine, guanine, thymine and uracil. The first four are the bases that make up DNA.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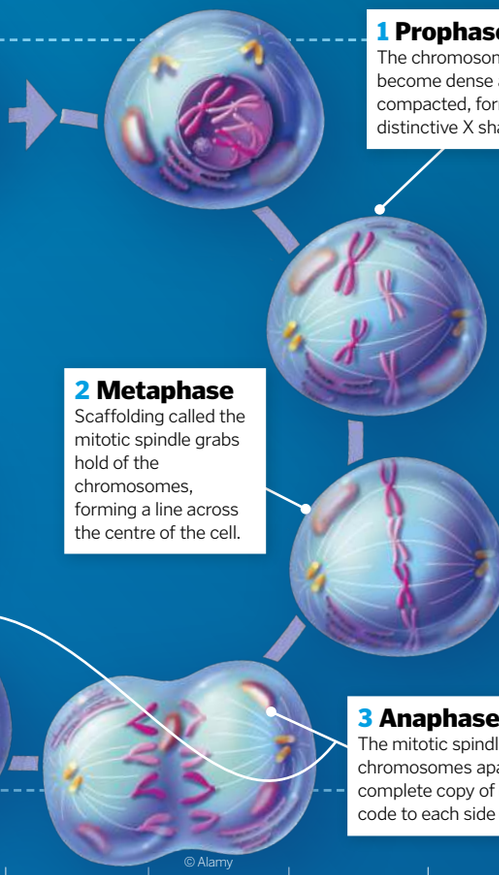
DID YOU KNOW? *The organism with the smallest genome is a bacterium called Carsonella ruddii, with just 182 genes*

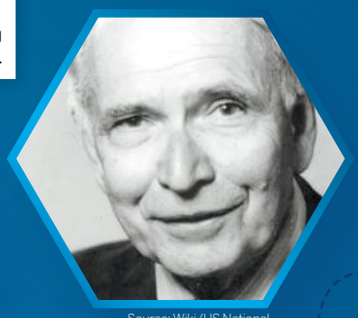


1 Prophase
The chromosomes become dense and compacted, forming distinctive X shapes.

2 Metaphase
Scaffolding called the mitotic spindle grabs hold of the chromosomes, forming a line across the centre of the cell.

3 Anaphase
The mitotic spindle wrenches the chromosomes apart, carrying a complete copy of the genetic code to each side of the cell.

© Alamy



Source: Wiki/US National Academy of Sciences

1953

FRANCIS CRICK & JAMES WATSON

© Getty © Getty

Crick and Watson solve the structure of DNA, revealing a ladder of bases surrounded by two ribbons of phosphates and sugars. They base their breakthrough on the work of other scientists, crucially Rosalind Franklin. Using Photo 51 for reference, they construct 3D models of DNA. They know from the work of Chargaff that bases come in pairs, and from the work of Linus Pauling that bonds between specific chemicals stick out at specific angles. At first they get the shape of thymine and guanine wrong, which makes fitting the pieces impossible. When Jerry Donohue suggests a different layout, the parts finally slot into place.

1950

Erwin Chargaff publishes his work on bases. He notices that DNA contains equal amounts of adenine and thymine and equal amounts of guanine and cytosine.

1959

Severo Ochoa and Arthur Kornberg receive a Nobel Prize for working out how cells make DNA.

1961

Marshall Nirenberg cracks the genetic code, working out how the letters correspond to the building blocks of proteins.

1996

Scientists in the UK become the first to clone a mammal from an adult cell: Dolly the sheep.

1977

Frederick Sanger invents Sanger sequencing, a way to read the letters of the genetic code.

2003

An international team publishes the first complete map of the human genome.

Source: Wiki/UnknownAuthor

1919

Phoebus Levene publishes his 'polynucleotide model', suggesting that DNA is a string of four types of nucleic acid.

© Getty

1952

MAURICE WILKINS

After working on radar during World War II, Wilkins moves to King's College London to capture images of DNA. Working together with graduate student Ray Gosling and biophysicist Rosalind Franklin, he uses X-rays to photograph the genetic code. He shares one of Franklin's photographs with Watson and Crick in Cambridge.

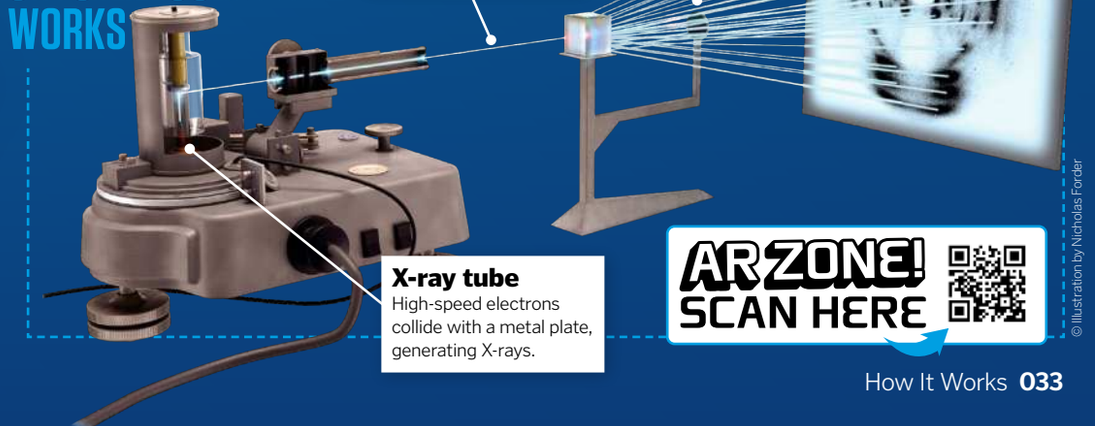
1952

ROSALIND FRANKLIN

Source: Wiki/Laboratory of Molecular Biology

Franklin captures Photo 51, revealing the helix shape of the DNA molecule. Her clear and striking photograph is instrumental in deciphering the structure of DNA, although Watson doesn't acknowledge that until after her death from ovarian cancer in 1958. Crick, Watson and Wilkins receive the Nobel Prize for the discovery of the structure of DNA four years later.

HOW X-RAY CRYSTALLOGRAPHY WORKS



X-ray beam
A slit focuses the X-rays into a narrow beam that strikes the crystal.

DNA crystal
The crystal contains thousands of DNA molecules, packed together with all their helix shapes aligned.

Photographic plate
The crystal diffracts the X-ray beam, scattering it onto a photographic plate in a pattern that reveals its structure.

X-ray tube
High-speed electrons collide with a metal plate, generating X-rays.

AR ZONE! SCAN HERE

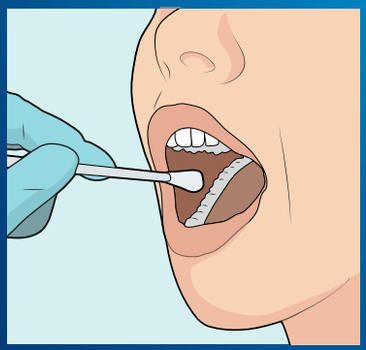
© Illustration by Nicholas Forder

DNA TODAY

THE SCIENCE OF DNA HAS ALREADY CHANGED THE WORLD WE LIVE IN

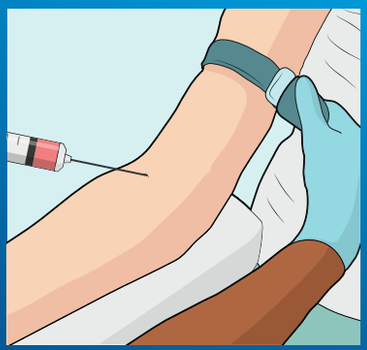
Taking samples

Cells and fluids taken in different ways hold the key to your unique genetic identity



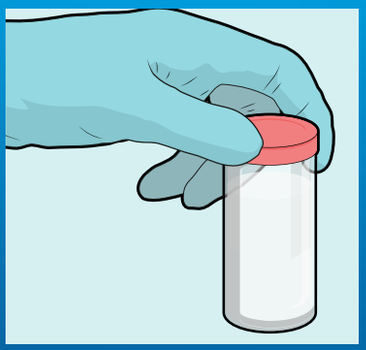
CHEEK SWAB

Gently rubbing the inside of the cheek removes the top layer of skin cells, providing enough DNA for testing.



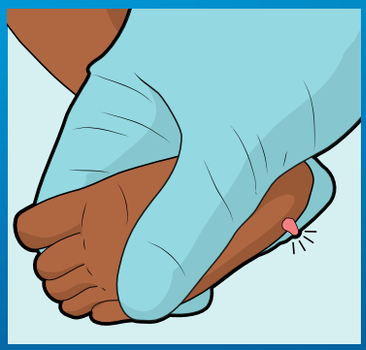
BLOOD TEST

Red blood cells don't contain DNA, so blood tests look at the genes in white blood cells.



SALIVA SAMPLE

Saliva contains cells from the cheeks, making spit samples an easy way to collect DNA at home.



HEEL PRICK

Tiny blood samples taken when babies are just a few days old can reveal problems in the blood caused by genetic conditions.

ARCHAEOLOGY

REBUILDING HISTORY

Skeletal remains can contain traces of ancient DNA for thousands of years. Extracting and sequencing this genetic material can reveal not only the sex of the individual – whether they had a Y chromosome or not – but also their ethnicity. This can help to retrace the steps taken by our ancestors as they spread across the world.

GENETIC HERITAGE (ANCESTRY)

ESTIMATING ETHNICITY

Ancestry is written into DNA like a fingerprint. Different populations of humans, separated by geography, develop their own unique mutations. These pass along from one generation to the next, leaving traces in genetic code. Comparing a genome against thousands of others can reveal where a person's ancestors came from.

FORENSICS

SOLVING CRIMES

Forensic scientists identify DNA by examining sequences called 'short tandem repeats'. These sequences occur in the gaps between genes and contain three or four DNA letters, repeated a different number of times in different people. Scientists count the number of repeats and compare them to repeats in a suspect's DNA.

GENE THERAPY

REPAIRING GENES

A handful of gene therapies are now licensed for use in human patients. These cutting-edge treatments use harmless viruses to carry healthy human genes into cells with genetic faults. The viruses paste these healthy genes into human DNA, fixing rare genetic disorders or killing cancer cells.

PATERNITY

IDENTIFYING FATHERS

Children inherit half of their genes from their mother and half from their father. In a paternity test, scientists compare around 15 genes from the mother, child and potential father to see how similar they are. Statistical analysis gives a score called a 'combined paternity index' – the likelihood of the person tested being the father.

PERSONALISED MEDICINE

MEDICINE FOR YOU

Tiny differences in our genes change the way illnesses affect us. A tumour might shrink in response to chemotherapy in one patient and not respond at all in another. Genetic testing can reveal which drugs might work best for which person, allowing doctors to match treatments to patients based on their unique genetic make-up.

"We will gain the power to repair, edit and rewrite our genes"

DNA testing can help to reveal the identity of unknown human remains

© Getty

© Getty

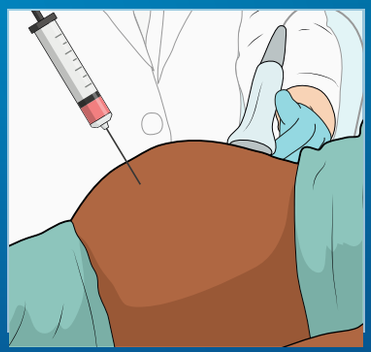
Genetic engineering can make plants resistant to pests and climate change

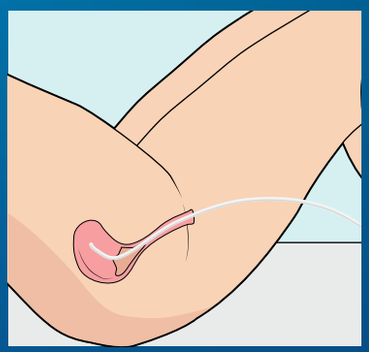
© Getty

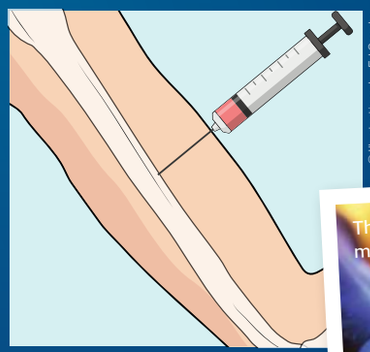
Gently swabbing the cheek dislodges enough cells for a DNA sample

THE FUTURE OF DNA SCIENCE

Over the next century, advances in DNA science are set to change the world forever. Armed with hundreds of thousands of unique human genome sequences, scientists are now working on the painstaking task of deciphering our genetic code. Understanding how each section of sequence controls the traits we inherit could lead to breakthroughs across dozens of different fields. It will tell us how we evolved, why we get sick and what happens as we age. As genetic engineering improves, we will gain the power to repair, edit and even rewrite our genes. Research scientists can already change the genes of laboratory animals, editing the letters to erase dangerous mutations and to enhance the traits that nature evolved on its own. As these techniques become safer, and as our understanding of our own genetics grows, we will gradually gain the power to change the genetic destiny of our species.







© Illustrations by Ed Crooks

AMNIOCENTESIS

Amniotic fluid contains skin cells from a developing baby. Extracting a small sample allows doctors to test for genetic conditions.

CHORIONIC VILLUS SAMPLING

The placenta is genetically identical to the developing foetus. Cells from the placenta can reveal genetic conditions early in pregnancy.

FINE NEEDLE ASPIRATION

Extracting a small number of cells from inside the body can reveal genetic changes in diseases like cancer.

These mice have a jellyfish gene that makes their skin and hair glow green

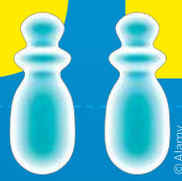
© Getty

DNA BY NUMBERS

99.9%
We share almost all of our DNA with other humans

6.41 PICOGRAMS
The male human genome weighs the same as six *E. coli* bacteria cells

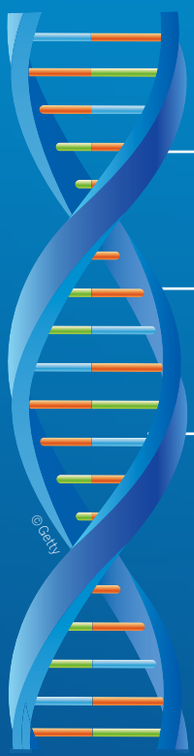
6.51 PICOGRAMS
The female human genome is a tiny bit heavier than its male equivalent



SPERM AND EGGS ONLY HAVE ONE SET OF CHROMOSOMES EACH

48 MILLION
The smallest human chromosome contains 48 million base pairs

249 MILLION
The biggest human chromosome contains 249 million base pairs

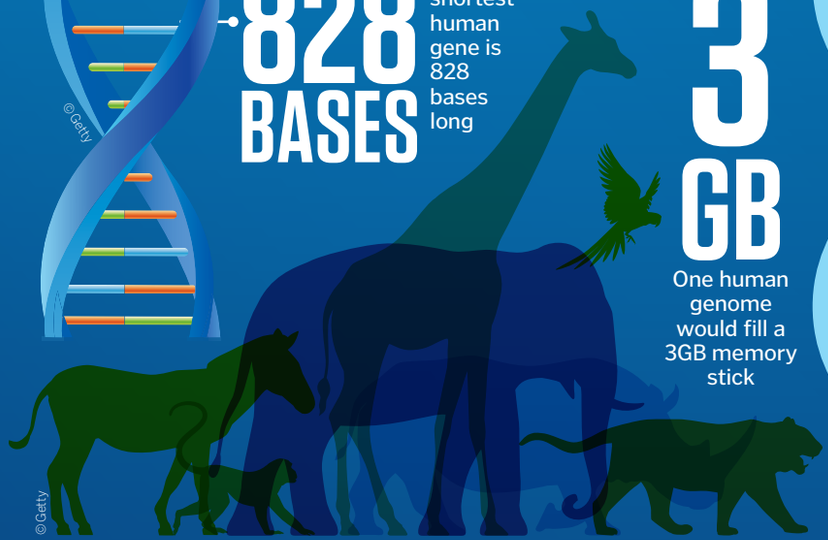


56,000 BASES
The average human gene is 56,000 bases long

2,400,000 BASES
The longest human gene is 2,400,000 bases long

828 BASES
The shortest human gene is 828 bases long

3 GB
One human genome would fill a 3GB memory stick

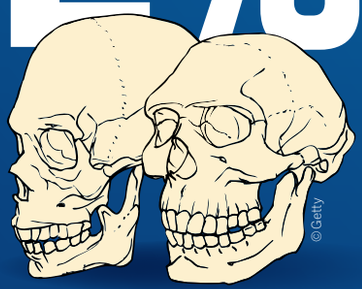


3 BILLION
It would take you around 300 years to count each of DNA's base pairs

25,000
The human genome contains around 25,000 genes

3
Each human gene codes for an average of three proteins

2%



NON-AFRICAN HUMANS SHARE TWO PER CENT OF THEIR DNA WITH NEANDERTHALS

ASIDE FROM SOME VIRUSES, EVERY ORGANISM ON EARTH HAS DNA

DNA STANDS FOR DEOXYRIBONUCLEIC ACID

$9,500 (£6,800)

It cost $9,500 (£6,800) to sequence a human genome in 2020

$300 (£216) MILLION

It cost $300 (£216) million to sequence a human genome in 2001

52,000

In 2012 scientists copied a 52,000-word book into DNA

98.5%

98.5% OF OUR DNA DOESN'T CONTAIN ANY GENES

42 BILLION MILES

There are 42 billion miles of DNA in the human body

50 BASES PER SECOND

DNA replicates at a speed of 50 bases per second

CHROMOSOMES ARE ONLY X-SHAPED JUST BEFORE CELLS DIVIDE

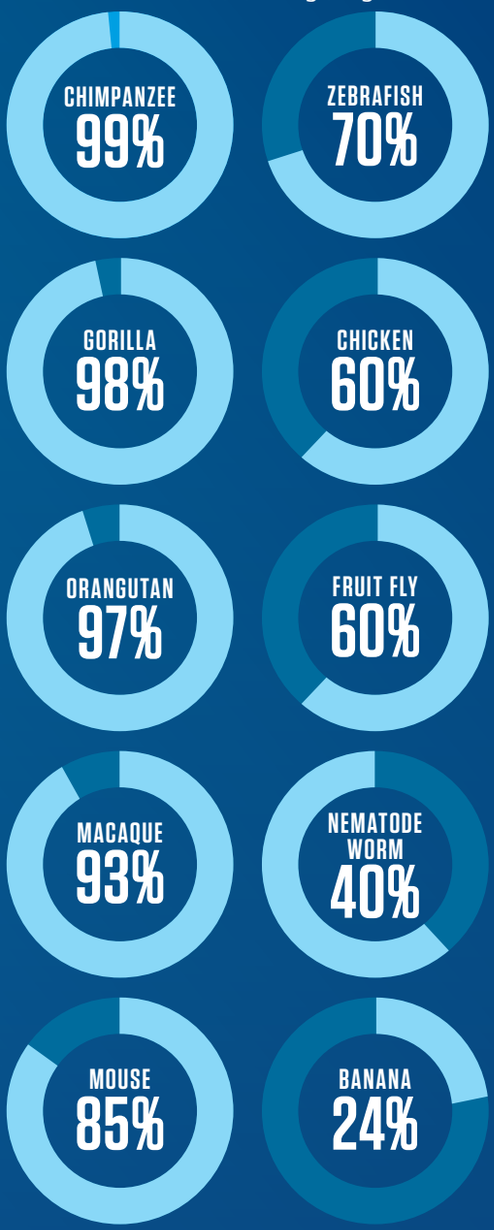
215 MILLION GIGABYTES

One gram of DNA can store 215 million gigabytes of data

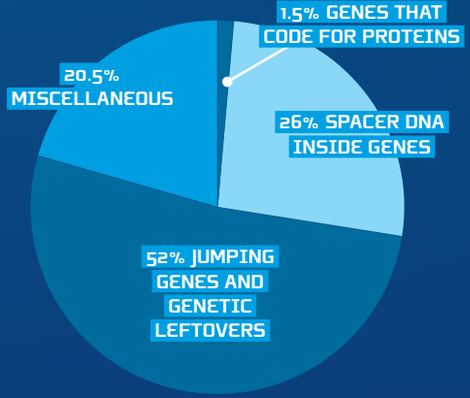
ALMOST A TENTH OF OUR DNA COMES FROM ANCIENT VIRUSES

NOT SO UNIQUE AFTER ALL

Humans share a surprising amount of DNA with other living things



WHAT'S IN A HUMAN GENOME?



Hydrogen: the unifying element

The most common element in the universe is actually quite rare here on Earth

Words by **Andy Extance**

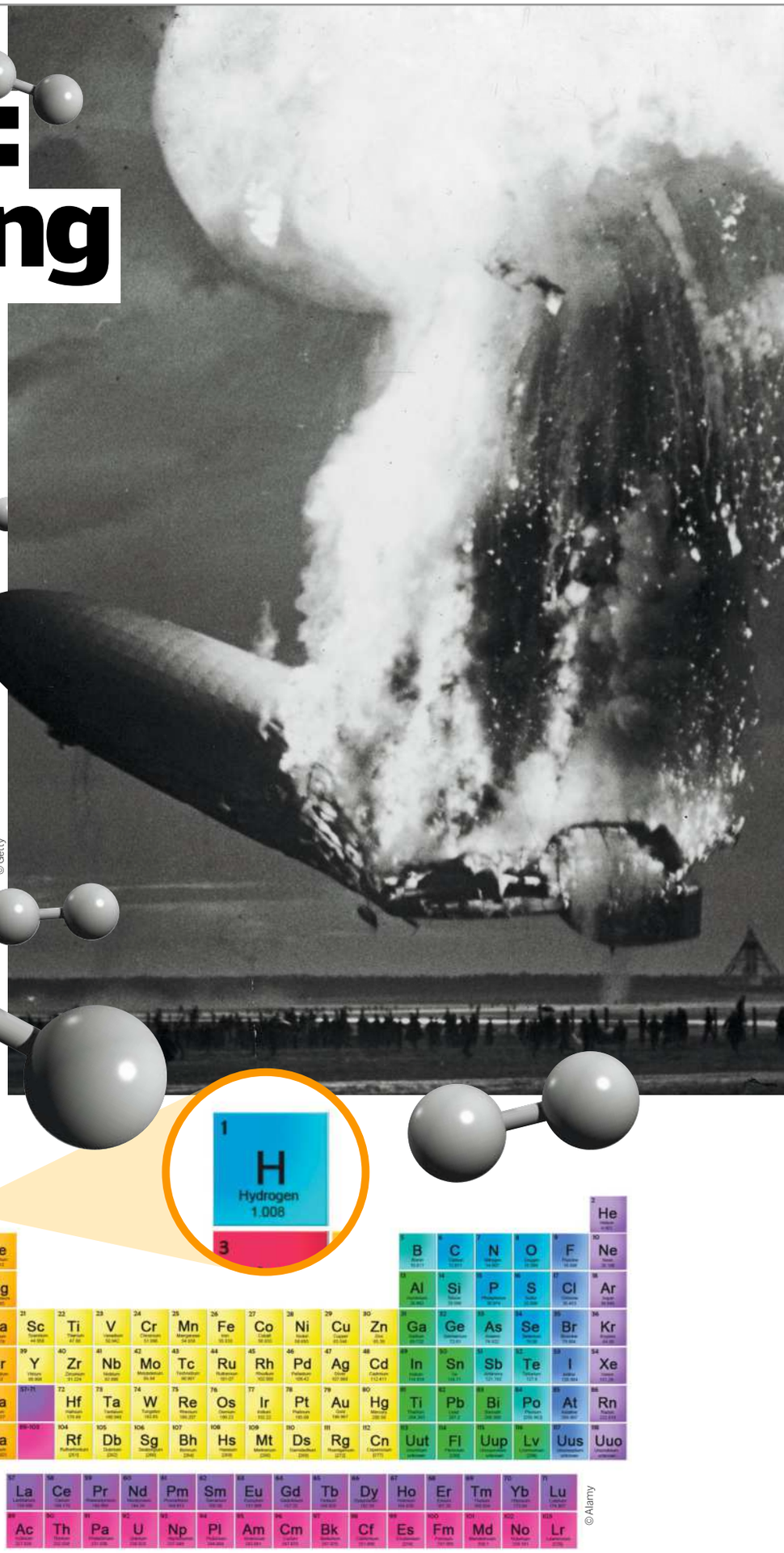
Hydrogen is the most important element there is. It is both dangerous and essential at the same time – just two of its amazing qualities. Hydrogen can be found in our bodies and many things around us. Also, hydrogen connects us all to the start of the universe – and all other things!

The special qualities of hydrogen start from its building blocks. In its most familiar form, hydrogen is the simplest element. Its atoms have just one proton and one electron. Like most other elements, it has isotopes with extra neutrons. But hydrogen is the only element with named isotopes. It's called deuterium when it has one neutron and tritium when it has two. This is more than just a curious fact – our lives rely on hydrogen's isotopes.

That's because at the heart of the Sun, hydrogen atoms fuse together to make deuterium. One proton becomes a neutron in the process, releasing energy that becomes the heat and light we rely on. This is a similar process to the one that happened following the Big Bang, making hydrogen and leading to all the other elements. Most of the hydrogen in our bodies and everything else was made then, tying us to the start of the universe.

This simple atomic structure makes hydrogen much lighter than air. It enabled human flight in airships until another of hydrogen's key properties had its say: it combines so well with oxygen that it burns easily, infamously destroying an airship called the Hindenburg in 1937. Yet as they burn, hydrogen and oxygen make water, which we need to stay alive.

Hydrogen reacts similarly well with many elements, making important substances. The materials hydrogen makes with carbon are the building blocks of living things like us. With so many important roles, hydrogen is truly the first among the elements.



© Getty
© Alamy

Hydrogen came first in the universe, and does in the periodic table too

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© Getty

"Hydrogen connects us all to the start of the universe"

Liquid hydrogen, burned together with oxygen, is the most efficient rocket fuel

Lots of hydrogen is used to remove polluting sulphur from natural gas

x3 Images © Getty

An elementary discovery

Some credit for discovering hydrogen goes to Theophrastus Philippus Aureolus Bombastus von Hohenheim. Better known as Paracelsus, around 1520 he recorded that dropping metals into strong acids released bubbles of gas. In 1650 Théodore de Mayerne repeated the experiment, discovering that the gas burned easily. But it wasn't until 1755 that people realised different types of gases existed.

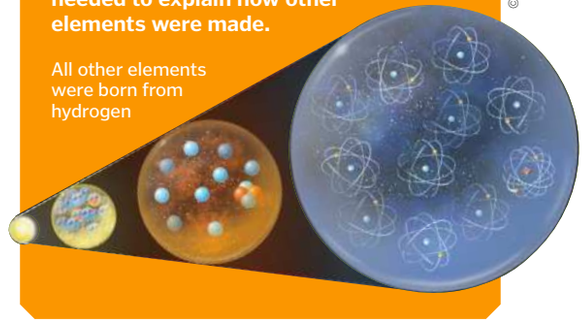
Soon after, the first person to work out that hydrogen was a unique substance was Henry Cavendish, who called it 'inflammable air'. At the time, some people thought that water and 'dephlogisticated air' – what we now call oxygen – were the only basic elements. In experiments from the 1760s and 1780s, Cavendish found that when inflammable air burned, it combined with dephlogisticated air to form water. That led French chemist Antoine Lavoisier to propose calling the gas hydrogen, as it is the gene, or creator, of hydro, which is Greek for water.

Henry Cavendish was the first to realise hydrogen was an element

© Getty

Born in the Big Bang

When he first thought it up, not everyone believed George Gamow's idea of how the elements were created. He suggested they formed by adding protons and neutrons together one at a time in the Big Bang. This happened when the universe was hot and dense, before it expanded and cooled rapidly. Working mainly with Ralph Alpher, Gamow saw the early universe as a highly compressed soup of neutrons. As the universe expanded, there would be room for neutrons to escape the soup and decay to make protons and electrons. From there hydrogen and deuterium might form, and then the other elements. Today this idea explains the large amount of hydrogen in the universe. However, other ideas were needed to explain how other elements were made.



All other elements were born from hydrogen

© Getty

How we use hydrogen

© Alamy

Rocket fuel

When burned together with oxygen, hydrogen is the most efficient rocket fuel there is. It has powered many space launches, including NASA's Space Shuttles. It's used as a liquid, meaning it must be kept very cold, which is difficult to do.

© Alamy

Oil refining

The UK alone uses 100,000 tonnes of hydrogen a year to turn natural gas and oil into useful products. When they come out of the ground, gas and oil contain sulphur, which creates pollution when it's burned. Hydrogen helps remove the sulphur.

© Alamy

Making fertiliser

Farmers can produce much more food than in the past thanks to fertiliser. This gives plants the nitrogen they need to grow in the form of ammonia. Large factories make ammonia from hydrogen and nitrogen from the air using the Haber-Bosch process.

© Alamy

Mining metals

A lot of the metals we use come out of the ground locked up together with oxygen in rocks. Because hydrogen reacts so well with oxygen, it can pull it away from the rock. This leaves pure metal in a usable form, and the only by-product of this is water.

THE POWER OF SOAP

WHEN HUMANITY INVENTED SOAP, IT CHANGED THE WORLD

Words by **Laura Mears**

In March 2020, soap sales in the UK more than doubled. This slippery, bubbly substance has a unique chemical make-up that allows it to rip through viruses, disintegrating microbes in milliseconds. It has truly been a lifesaver during the coronavirus pandemic.

Invented in the ancient world, the first soap was just a paste made from fat and ash. People discovered it while trying to remove grease from wool, noticing that mixing burnt wood with water made the process easier. At a microscopic level, alkalis in the ashes were reacting with fats in the grease to create soap molecules. Over time, people refined the soap-making process, learning to boil the fat and ash together to create soap before applying it to their cloth.

By the Middle Ages, soap makers had started to spring up in Europe, where cloth manufacture was big business. They chopped down huge woodlands to make ash and mixed that ash with whatever fat they had available. In the north, this was tallow made from animal fat. Unfortunately, tallow was an essential ingredient for making candles. To keep candle prices low, soap making was taxed, and soap was reserved for cleaning cloth.

"Soap rips through viruses, disintegrating microbes in milliseconds"

© Getty

Soap has revolutionised healthcare by helping to stop the spread of germs

It wasn't until the 1800s that the cleaning power of soap was properly unleashed. Around that time, illnesses like typhoid and cholera were rife. Most people didn't have easy access to running water, and many believed that washing their skin would cause disease. But this was the century of sanitation, and that was all about to change.

How soap is made

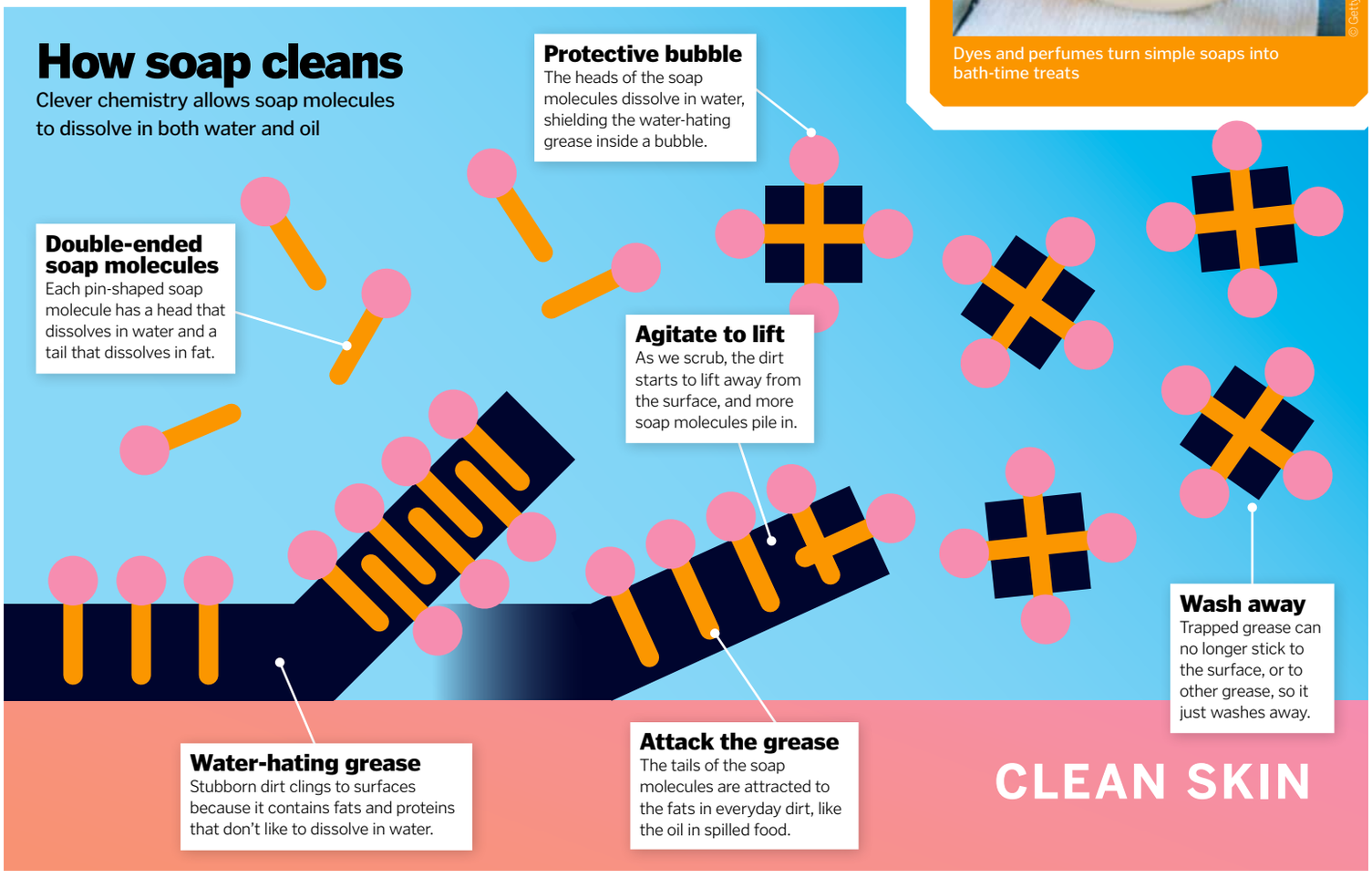
You only need two ingredients to make soap: an alkali, like sodium or potassium hydroxide, and a fat, like tallow or olive oil. The fat supplies molecules called triglycerides, which have a backbone made from glycerol. That glycerol is attached to three fatty acids by bonds called esters. When you mix triglycerides with an alkali and apply heat, the ester bonds snap, releasing the fatty acids from the glycerol. The alkali then neutralises the acids, and this is what forms the soap molecules. Each neutralised molecule has a fatty acid tail at one end, and a charged 'head' at the other. This makes them 'amphiphiles' – a word that literally means 'both love' – describing their ability to dissolve in both fat and water.

© Getty

Dyes and perfumes turn simple soaps into bath-time treats

How soap cleans

Clever chemistry allows soap molecules to dissolve in both water and oil



Louis Pasteur proved that germs made people sick, John Snow noticed that cholera outbreaks were spread by dirty water and doctors made the link between hand hygiene and the transmission of infections. As a result, local governments started to install sanitation infrastructure in towns and cities, building sewers, digging drainage and supplying their populations with clean water. And in 1853 the soap tax was finally lifted.

Soap manufacturers started to put effort into making gentler soaps for use on skin, adding perfumes and dyes to make their products more appealing. And people finally started using it to wash their hands and bodies, completely revolutionising personal hygiene.

Soaps aren't just for cleaning; they're added to oils to make machine grease

© Getty

© Getty

Soap lifts stubborn stains from clothes by dissolving grease and grime

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VS

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SOAP

Soap is the gold standard when it comes to keeping your hands clean. It does more than just kill microscopic bacteria and viruses; it also removes visible dirt and harmful chemicals from the skin. Its grease-lifting action attacks all kinds of everyday grime, from melted chocolate to garden pesticides. But to use it properly you need access to running water, making it a difficult option for people on the move. It's also slightly less effective on viruses that have a protein shell instead of a fatty membrane. These include rhinoviruses, which cause the common cold. Soap can break rhinoviruses down, but hand sanitiser works faster.

SANITISER

Hand sanitiser is soap's portable relative. It contains powerful chemicals – either ethanol or isopropyl alcohol – which, like soap, disrupt the fatty barriers that protect bacteria and viruses. But unlike soap, it also tears through the protein shells that surround rhinoviruses. It does have some disadvantages, however. Hand sanitiser works best on visibly clean hands; it can't get rid of grease, and it becomes less effective at killing viruses when your hands are dirty. For the best results, choose a mixture that contains between 60 and 95 per cent alcohol, and keep rubbing your hands together until they are dry.

History of soap

Source: Wiki/Laurentius

2800 BCE
Ancient Sumerians start cleaning wool with mixtures of ashes and fat.

1550 BCE
Ancient Egyptians coat their skin with pastes made from oil and soda ash.

600 BCE
Ancient Phoenicians make laundry soap using goat tallow and burnt wood.

100 CE
A Greek doctor, Galen, notices that soap is good for cleaning the body.

Source: Wiki/Liana

700 CE
An Arab chemist, Geber, writes about using soap as a way to keep clean.

1200 CE
Soap makers start to appear in England, but soap production is heavily taxed.

Source: Wiki/Knight1817

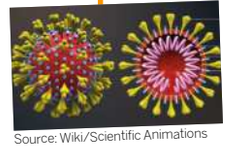
1600
Soap is so rare in Europe that most common people have no idea how to use it.

1853
The soap tax in England is finally abolished, and washing becomes more common.

Source: Wiki/Spl1nd01

1914
Oil shortages during World War I drive German scientists to invent the first synthetic detergents.

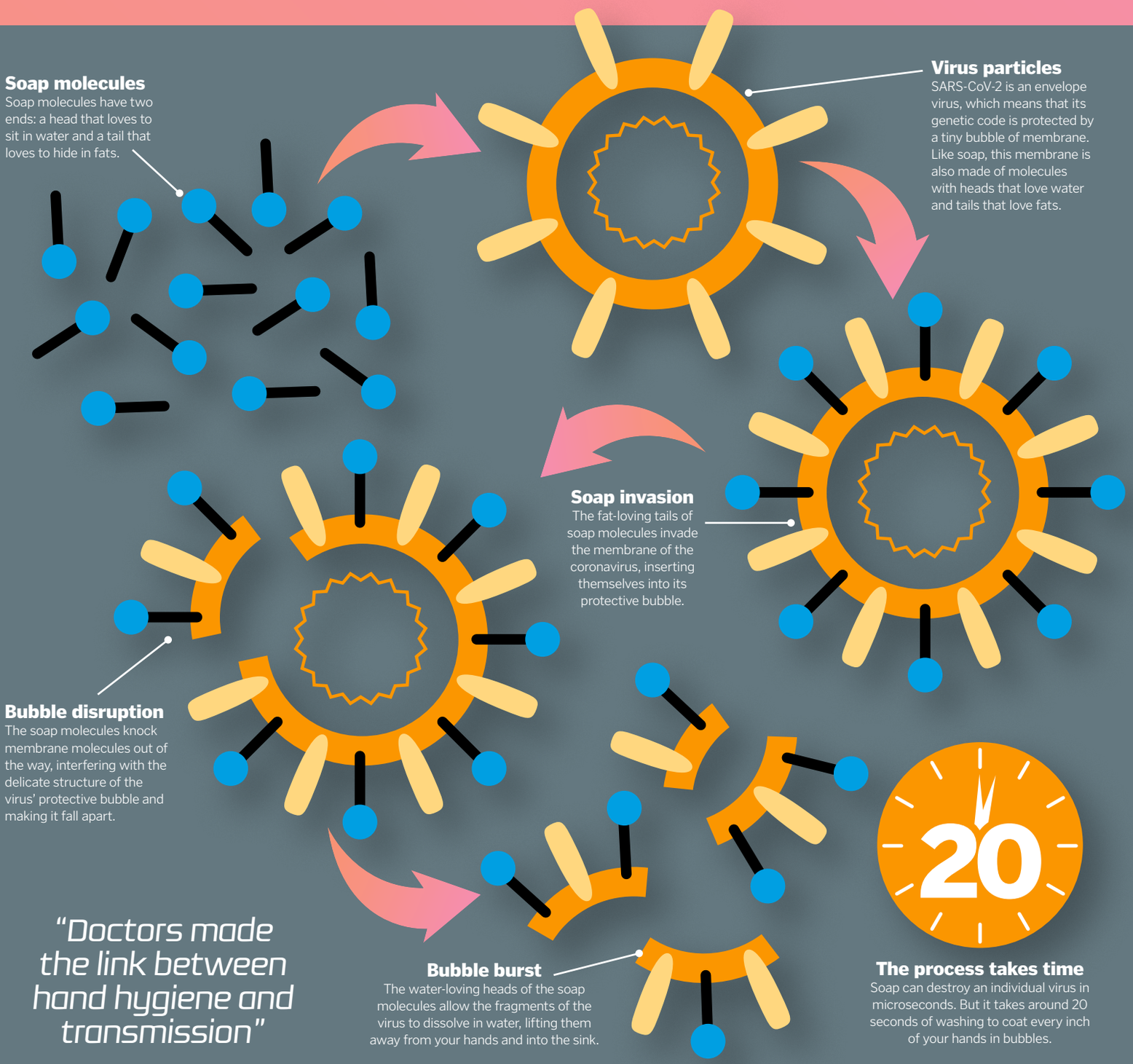
2019
Soap becomes humanity's first line of defence against the coronavirus pandemic.



Source: Wiki/Scientific Animations

HOW SOAP KILLS CORONAVIRUS

SIMPLE SOAP IS ONE OF THE BEST DEFENCES WE HAVE AGAINST COVID-19



Soap molecules
Soap molecules have two ends: a head that loves to sit in water and a tail that loves to hide in fats.

Virus particles
SARS-CoV-2 is an envelope virus, which means that its genetic code is protected by a tiny bubble of membrane. Like soap, this membrane is also made of molecules with heads that love water and tails that love fats.

Soap invasion
The fat-loving tails of soap molecules invade the membrane of the coronavirus, inserting themselves into its protective bubble.

Bubble disruption
The soap molecules knock membrane molecules out of the way, interfering with the delicate structure of the virus' protective bubble and making it fall apart.

Bubble burst
The water-loving heads of the soap molecules allow the fragments of the virus to dissolve in water, lifting them away from your hands and into the sink.

20

The process takes time
Soap can destroy an individual virus in microseconds. But it takes around 20 seconds of washing to coat every inch of your hands in bubbles.

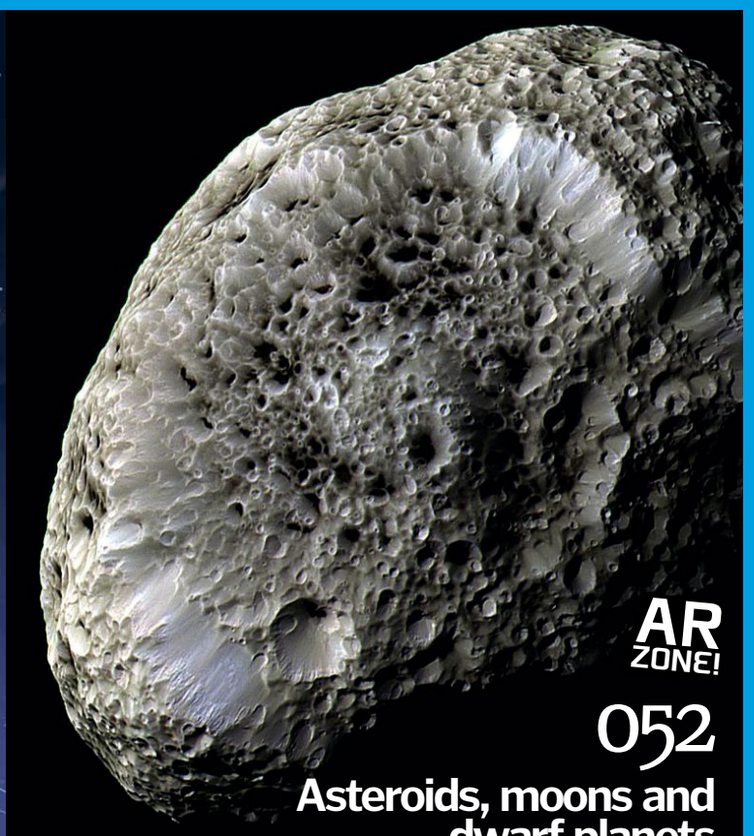
"Doctors made the link between hand hygiene and transmission"

SPACE

AR ZONE!

058
The Hidden universe

AR ZONE!



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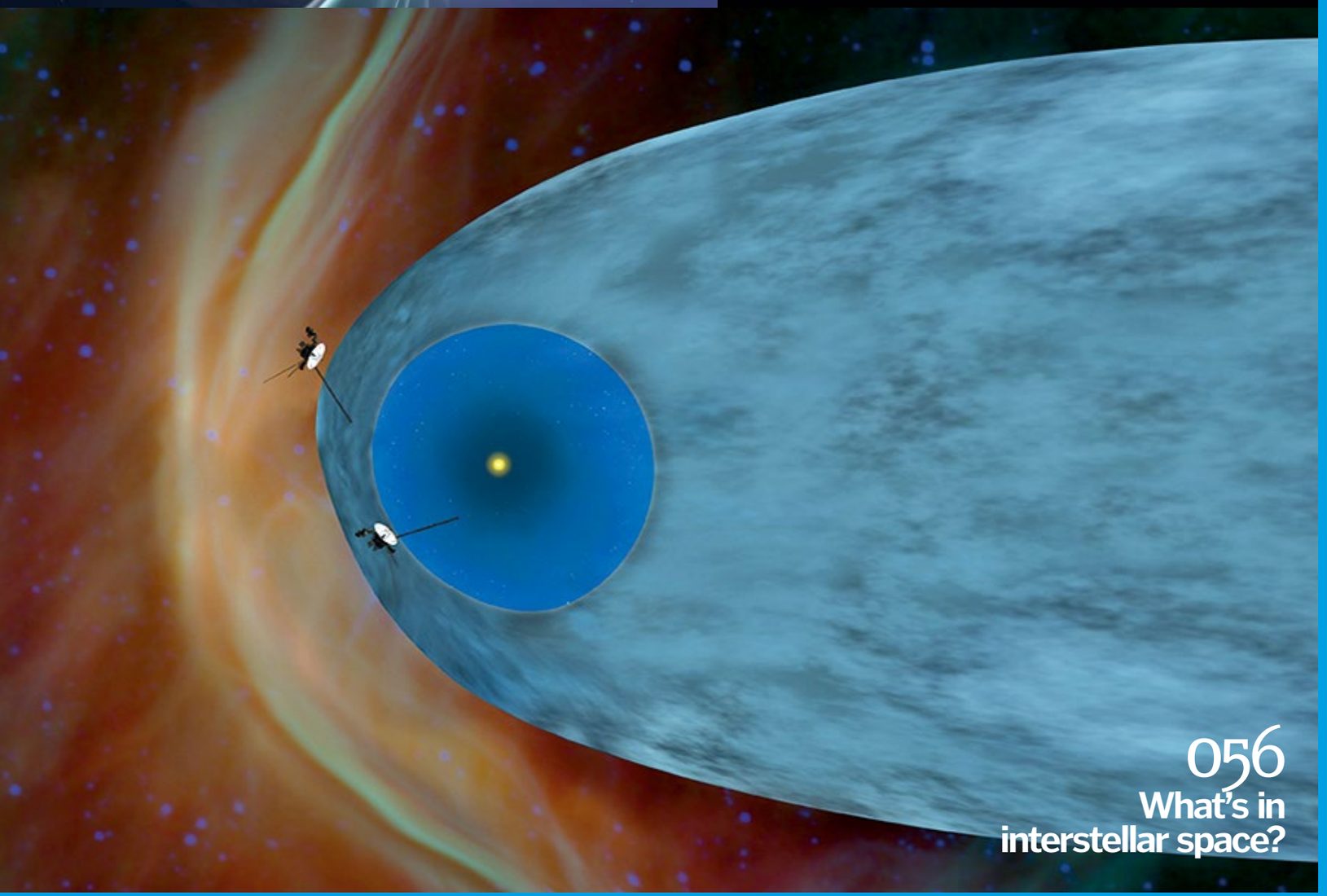


DETECTING SPACE HA

ZARDS

How the ESA's Space Situational Awareness programme is tackling dangers in space

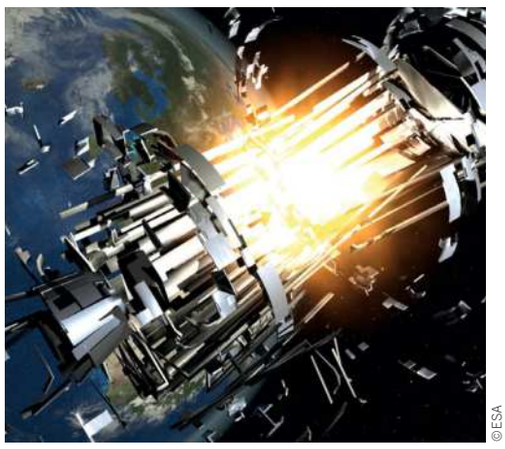
Words by **Andrew May**

Threats from outer space: it sounds like science fiction, but at some level Earth has always been vulnerable to them. Think of the giant asteroid that wiped out the dinosaurs 66 million years ago. Fortunately such occurrences are extremely rare, but there are other natural phenomena – in the form of solar storms – that can strike from space much more frequently.

These have little effect on living things, but they can play havoc with the electronic systems we increasingly depend on, with satellite-based technology in particular at risk of being affected. To make matters worse, the proliferation of the latter has created a new space hazard of its own in the form of orbiting debris with the potential to destroy other satellites.

Numerous organisations around the world have been set up to address these threats, but it's usually done in a piecemeal fashion. In America, for example, the tracking of space debris is carried out by the US Space Force, the monitoring of 'space weather' is coordinated by the National Oceanic and Atmospheric Administration and the search for potentially hazardous asteroids is the job of NASA's grandly named Planetary Defense Coordination Office. The European Space Agency (ESA), on the other hand, has adopted a unified approach to all these activities under the umbrella of its Space Situational Awareness programme. Set up in 2009, this is divided into three segments covering space weather, near-Earth objects and space surveillance and tracking.

The emphasis in all three areas is on the detection and tracking of potential threats. As long as these are known in advance, appropriate action can be taken to minimise danger. The projected impact site of an asteroid can be evacuated, for example, or a satellite on a collision course with a piece of space debris can be moved to a different orbit.



Fuel left in old rocket stages can explode, creating a cloud of space debris

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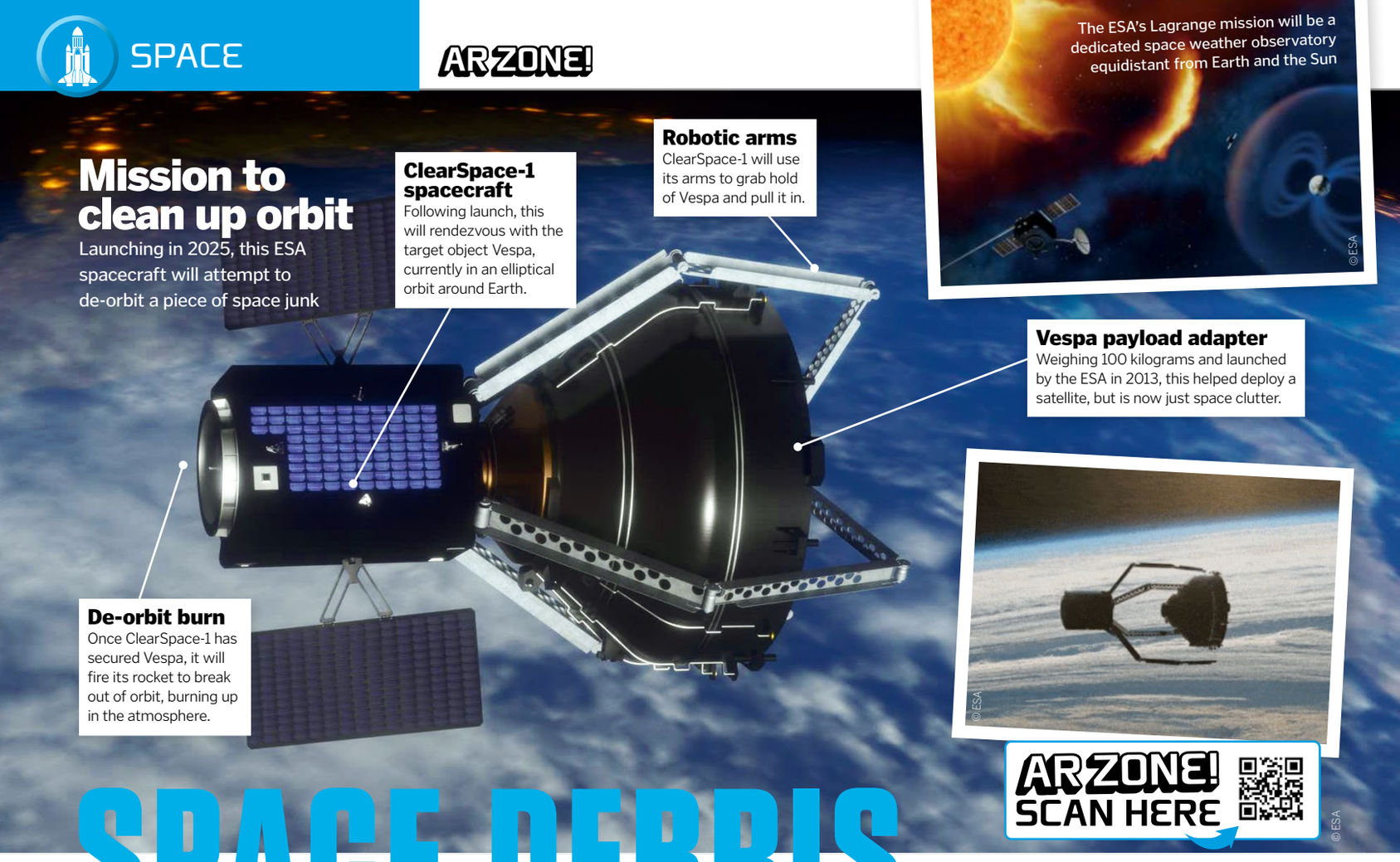

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SPACE DEBRIS

The satellites we depend on for communication, navigation and environmental monitoring are under increasing threat from all the junk that's up there in orbit with them. This includes derelict satellites and the rocket stages used to launch them, but if that was the extent of the problem there would be a manageably small number of objects to keep track of.

Unfortunately, those objects have a tendency to multiply, partly due to explosions caused by residual fuel and partly through collisions. Events like these can create thousands of smaller fragments, which due to their high speed and random orbits, pose at least as much risk as the original object.

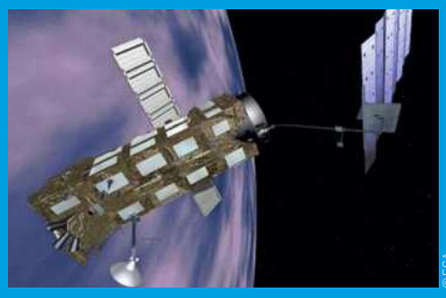
Working satellites are equipped with manoeuvring thrusters so they can be moved to a different orbit if it's known that a piece of space debris is heading their way. With tens of thousands of objects large enough to cause serious problems, though, it's no easy task to keep track of all of them. Yet that's exactly what the space surveillance and tracking segment of the ESA's Space Situational Awareness programme has to do. It employs a network of telescopes, radars and laser-ranging stations to detect and track objects, then processes the resulting data at ESA mission control in Darmstadt, Germany. The latter will issue an alert if evasive action is deemed necessary.

This system works well at the moment, but that won't always be the case. If things carry on as they are, the space debris problem will get much worse in the future. The number of new satellites being launched is higher than it has ever been, while the number of fragmentary objects is increasing due to ongoing collisions. The worry is that the amount of space debris could reach a tipping point, beyond which there is a continuous cascade of self-generating collisions. Known as Kessler syndrome, this would render certain orbits unusable if it continued unchecked. For this reason the ESA is also considering methods for the active removal of space debris. Its ClearSpace-1 mission, if it goes according to plan, will be the first in the world to remove a piece of space debris from orbit.

Space debris can travel at speeds of up to 17,500 miles per hour when orbiting the Earth

The space junk top 50

Although there are thousands of pieces of space junk, the most serious threats, not surprisingly, come from the largest objects. In October 2020, the International Astronautical Congress (IAC) was presented with a list of the 50 statistically most concerning debris objects. These were ranked not just by size, but also the persistence of their orbits and the likelihood of colliding with another object. More than three-quarters of the top 50 are spent launch stages that remain in orbit, while 80 per cent originated in the 20th century, before space agencies started taking specific measures to limit orbital debris. The ESA has the dubious honour of having the top-ranked satellite on the list – the now-defunct environmental monitoring satellite Envisat, launched in 2002.



The ESA's Envisat, which has been derelict since 2012, is a potential space hazard

OUR COSMIC JUNKYARD

1,950

DISCARDED ROCKET STAGES

Although the lower stages of launch rockets fall back to Earth, the upper stages often end up in orbit.

2,850

DEFUNCT SATELLITES

Although satellites usually de-orbit at the end of their life, they may fail prematurely and end up stuck in orbit.

21,000

UNIDENTIFIED DEBRIS OBJECTS

This category covers objects large enough to be observed and tracked, but too small to identify specifically.

34,000

FRAGMENTS OVER TEN CENTIMETRES

These are below the threshold for surveillance and tracking, but numbers can be estimated.

900,000

FRAGMENTS UP TO TEN CENTIMETRES

Even at this small size, objects can inflict considerable damage in a collision if the relative speed is high.

128 million

FRAGMENTS UP TO ONE CENTIMETRE

At the smallest size, serious damage is unlikely, but there can be cumulative sandblasting-like degradation, especially to solar panels.

HOW THIS JUNK IS CREATED

Propulsion: 39.52%
Unspent fuel in tanks and rocket thrusters can explode accidentally, for example due to heat stress.

Anomalous: 5.64%
Parts of a satellite that are meant to stay attached, such as solar panels or insulation, may accidentally break loose.

Collision: 9.01%
If one satellite is hit by another, or by space debris, the result is likely to be yet more debris.

Electrical: 6.4%
As with fuel explosions, satellites can also be destroyed by exploding batteries, although this is less common.

Deliberate: 23.77%
In the past, before fragmentation hazards were understood, satellites were sometimes blown up at the end of a mission.

Unknown: 14.29%
Objects here probably belong to one of the other categories, but there is insufficient evidence to say which.

Accidental: 0.8%
In a small number of cases, satellites may break up simply because they were badly designed.

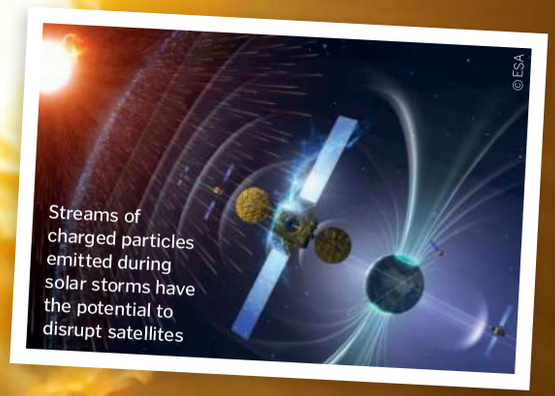
Aerodynamics: 0.56%
Because satellites in low-altitude orbits are not in total vacuum, some have been broken up by atmospheric drag.

MONITORING SPACE WEATHER

On Earth, the main source of space weather is the Sun. The Sun was here before the Earth, and space weather events such as solar flares and coronal mass ejections (CME) have been occurring since before life began. But it's only in the modern world that they've become a significant hazard. As long as people stayed at ground level and didn't rely on electronic systems for navigation and communication, or on the electrical grid for power, they could remain blissfully unaware of solar activity. But in today's world, with all our satellites and electronic aids, that's no longer an option. Someone has to keep a constant eye on the vagaries of space weather, just as meteorologists do with ordinary weather.

The way space weather forecasters work is analogous to their terrestrial counterparts, combining data from a variety of sources – both on the ground and in space – with computer models to work out what's likely to happen. Unlike terrestrial forecasts aimed at the general public, space weather forecasts are targeted at the business sectors most likely to be affected. The ESA's Space Weather Network provides tailored services to a variety of industries, ranging from airlines and power distribution systems to spacecraft operators and auroral tourist agencies.

As with ClearSpace-1, the ESA's space weather segment is planning a world first. Although numerous satellites operated by the ESA, NASA and other agencies contribute to the space weather picture, they all perform other tasks as well. In contrast, the ESA's Lagrange spacecraft will be the first to focus solely on space weather. To this end, it will be positioned 'side-on' to the Earth-Sun axis, at equal distances from both, to give it the best possible view of solar storms heading towards our planet.



Streams of charged particles emitted during solar storms have the potential to disrupt satellites

How space weather affects us

Solar storms, either in the form of radiation or ejected matter, have many adverse effects

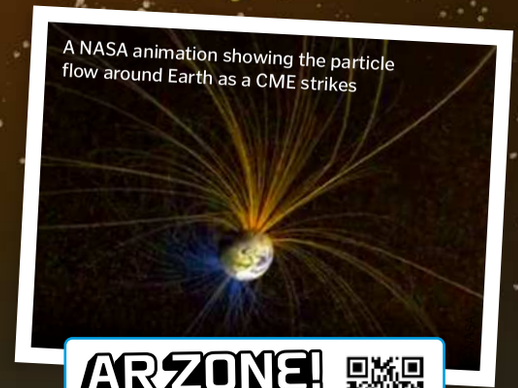
Coronal mass ejection
This is where material from the Sun is blasted out like a cannonball – if we're unlucky, it may hit Earth.

Solar energetic particles
Solar flares or CMEs may be accompanied by streams of high-energy protons and electrons, which can also cause disruption.

Solar flare
If a CME is a cannonball, then a solar flare is a muzzle flash – an intense burst of high-energy radiation.

Solar panel degradation
Space weather takes a steady toll on a satellite's solar panels, which generate less and less power over time.

Astronaut irradiation
Although astronauts are subjected to relatively low levels of radiation, this has a cumulative effect on long-duration missions.


A NASA animation showing the particle flow around Earth as a CME strikes

Satellite damage
Electronic systems in satellites can also suffer damage, especially during severe space weather events.

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Aurorae
On a positive note, solar activity can produce spectacular auroral displays at high latitudes.

Irradiation of aircraft
The main concern is for crew members who are in the air a lot, rather than passengers who only fly occasionally.

Navigation errors
Satellite navigation services can be disrupted by space weather, causing serious consequences for ships and aircraft that rely on them.

Radio wave disturbance
Even at ground level, radio communications can be disrupted by severe solar storms.

Satellite reception
Satellite communication systems, including satellite TV, can also fall victim to space weather events.

Power grid
A solar storm can induce stray currents in electrical power lines, leading to disruption of power supplies.

NEAR-EARTH OBJECTS

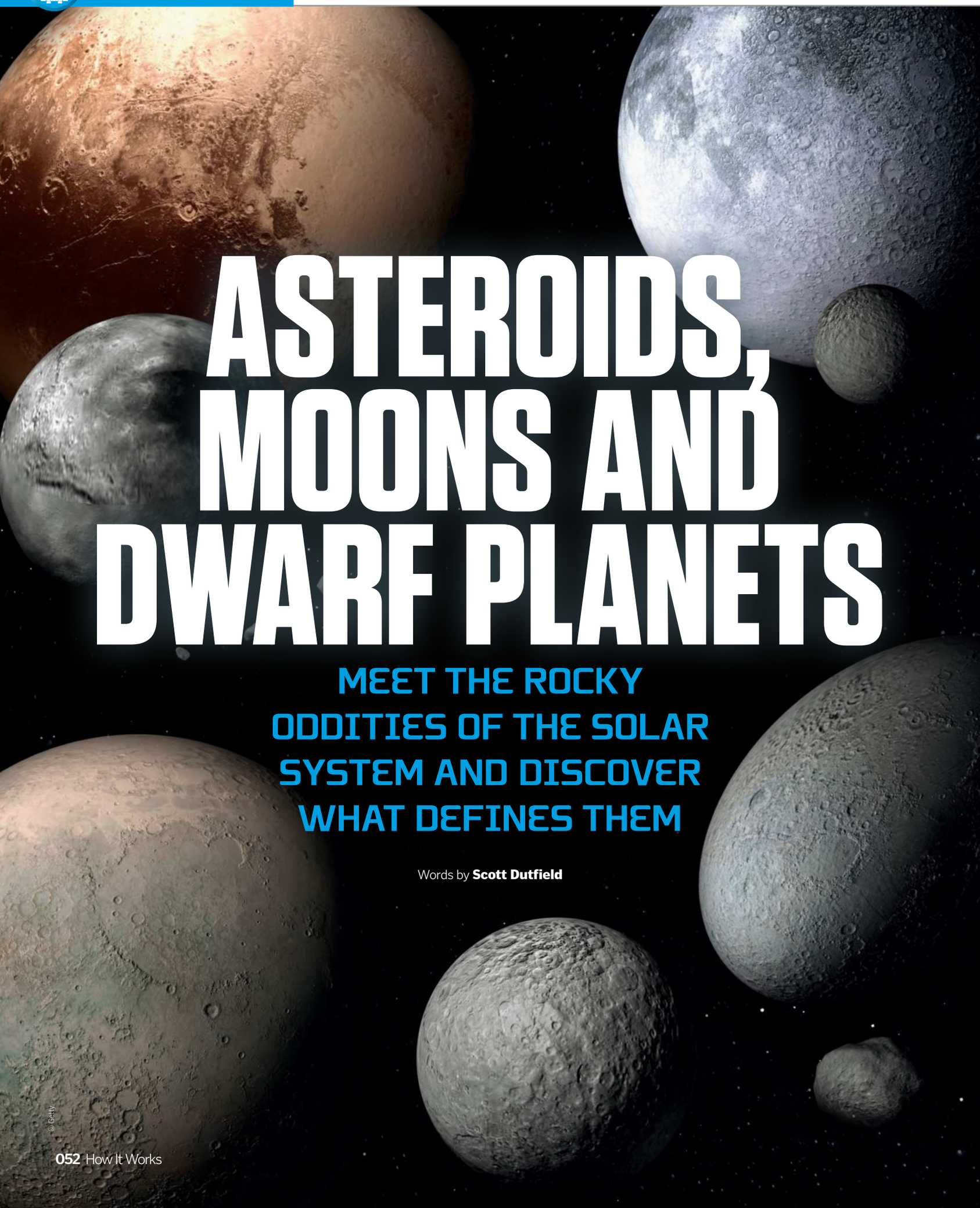
Their name is slightly misleading, because near-Earth objects (NEOs) aren't always near Earth – they may be hundreds of millions of miles away on the other side of the Sun. But they're moving on orbits that cross Earth's orbit, or come close to it, which raises the risk of a future collision.

This doesn't necessarily spell disaster, because many NEOs are so small they will burn up as they enter the Earth's atmosphere. When it comes to asteroids or comets large enough to inflict serious damage, however, these can usually be detected by telescopes when they're still a long way from an impact. This is where the NEO segment of the ESA's Space Situational Awareness programme comes in.

The NEO segment is made up of a number of components, including a Europe-wide network of observers – both professionals and volunteers – to determine the current positions of NEOs. These observations then feed into a central analysis team, which uses the data to predict future orbits, assesses the collision risk and – if necessary – issues warnings to civil authorities if the predicted impact point lies inside Europe. The ESA is also investigating ways to deflect an incoming NEO before it hits Earth.

Artist's impression of a pair of asteroids passing close to Earth

DID YOU KNOW? *A 20-metre asteroid exploded over Russia in 2013, causing a huge shock wave*



ASTEROIDS, MOONS AND DWARF PLANETS

MEET THE ROCKY ODDITIES OF THE SOLAR SYSTEM AND DISCOVER WHAT DEFINES THEM

Words by **Scott Dutfield**

Our Solar System is essentially made up of different sized and shaped rocks, and a couple of big balls of gas, which are all orbiting a hydrogen-burning behemoth we call the Sun. To give this interconnected system order, scientists throughout history have categorised the Solar System's largest celestial bodies into terrestrial planets, gas giants and ice giants. But what about the smaller stuff?

Dwarf planets, moons and asteroids fill our Solar System. At the current count there are five dwarf planets, over 200 moons and between 1.1 and 1.9 million asteroids that are over 0.6 miles in diameter residing in the Solar System. But how do you define what's what? There is a whole host of criteria that the International Astronomical Union (IAU) has outlined to determine whether a celestial body is a dwarf planet, moon or asteroid.

In brief, a dwarf planet is a celestial body that orbits the Sun and assumes an approximate spherical shape, and has also cleared the area around its orbit of other comparatively sized bodies. Moons, on the other hand, are natural satellites that orbit other larger celestial bodies. However, the IAU provides no scientific definition of what it means to be a moon.

Asteroids are smaller than planets and moons, but share the behaviour of orbiting the Sun. These rocks fail to meet the classification criteria of planets and dwarf planets, particularly because of their lack of mass and irregular shapes. Like wood shavings on the floor of a carpenter's workshop, asteroids are leftover chunks of rock from when the Solar System formed. They can vary in size and shape, but all of them have a mass smaller than Earth's Moon.

The majority of asteroids in the Solar System can be found in the asteroid belt, which sits between Mars and Jupiter, though some trojan asteroids share the orbit of other planets. 150 known asteroids also have a smaller companion, such as the asteroid Ida and its mini-moon Dactyl.

Dwarf planets, moons and asteroids have been circling the Sun ever since our Solar System formed 4.6 billion years ago, but it wasn't until the early 1800s that scientists around the world started recording the existence of dwarf planets.

The earliest dwarf planet discovered, called Ceres, sits between Mars and Jupiter and only spans 580 miles in diameter. It was spotted by Italian astronomer Giuseppe Piazzi in 1801. Because of its relatively minute size – around 0.015 per cent of Earth's – Ceres was initially classified as both a dwarf planet and an asteroid. The first study of moons, on the other hand, is more tricky to pinpoint, considering there's one that's been noticeably sitting in our sky since before humans were capable of asking what it was. However, the Nebra sky disk, an ancient artefact dating back around 3,800 years, is thought to be the first known depiction of the cosmos, and includes Earth's Moon.

Types of asteroid

There are three types of asteroid, and each differs in composition

1 C-type
Also known as carbonaceous chondrite asteroids, around 80 per cent of the asteroids in the outer edges of the asteroid belt are C-type rocks. These, almost coal-black asteroids contain large amounts of carbon and are mostly solid, indicating that they may have been molten at some point in time.

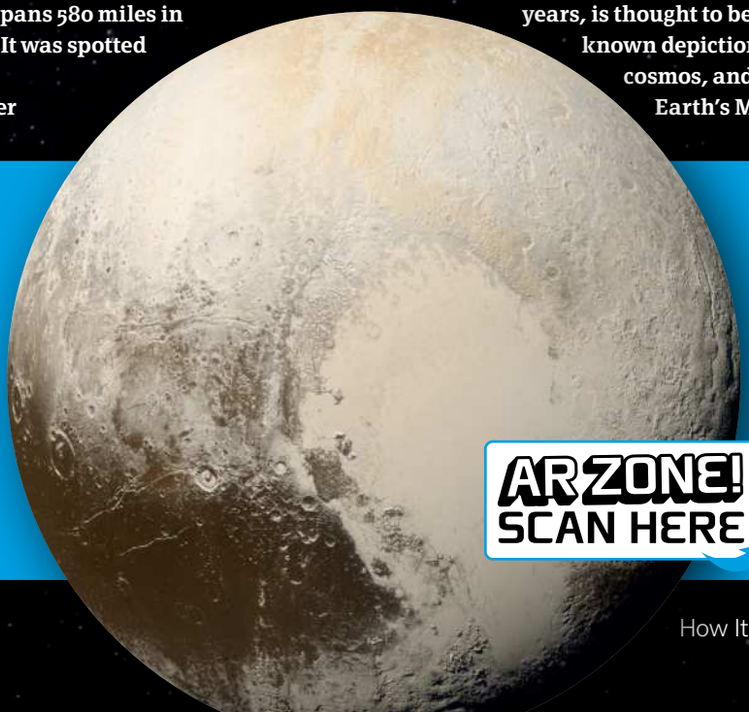
2 S-type
These are stony asteroids that contain both silicates and nickel-iron metal. They also appear brighter than the dark, carbonaceous chondrite C-type asteroids. These stony S-type asteroids make up nearly a fifth of all known asteroids in the Solar System.

3 M-type
Metallic asteroids are mostly made of nickel and iron. The differences in their composition relate to their proximity to the Sun. During their formation, while exposed to high temperatures close to the Sun, these asteroids were partly melted. This resulted in the formation of an iron core and basaltic surface.

The problem with Pluto

Arguably one of the most controversial decisions ever made in the field of astronomy, in 2006 the International Astronomical Union announced that the planet at the end of the Solar System would be stripped of its planetary status. Joining the likes of Eris and Ceres, Pluto was demoted to dwarf planet.

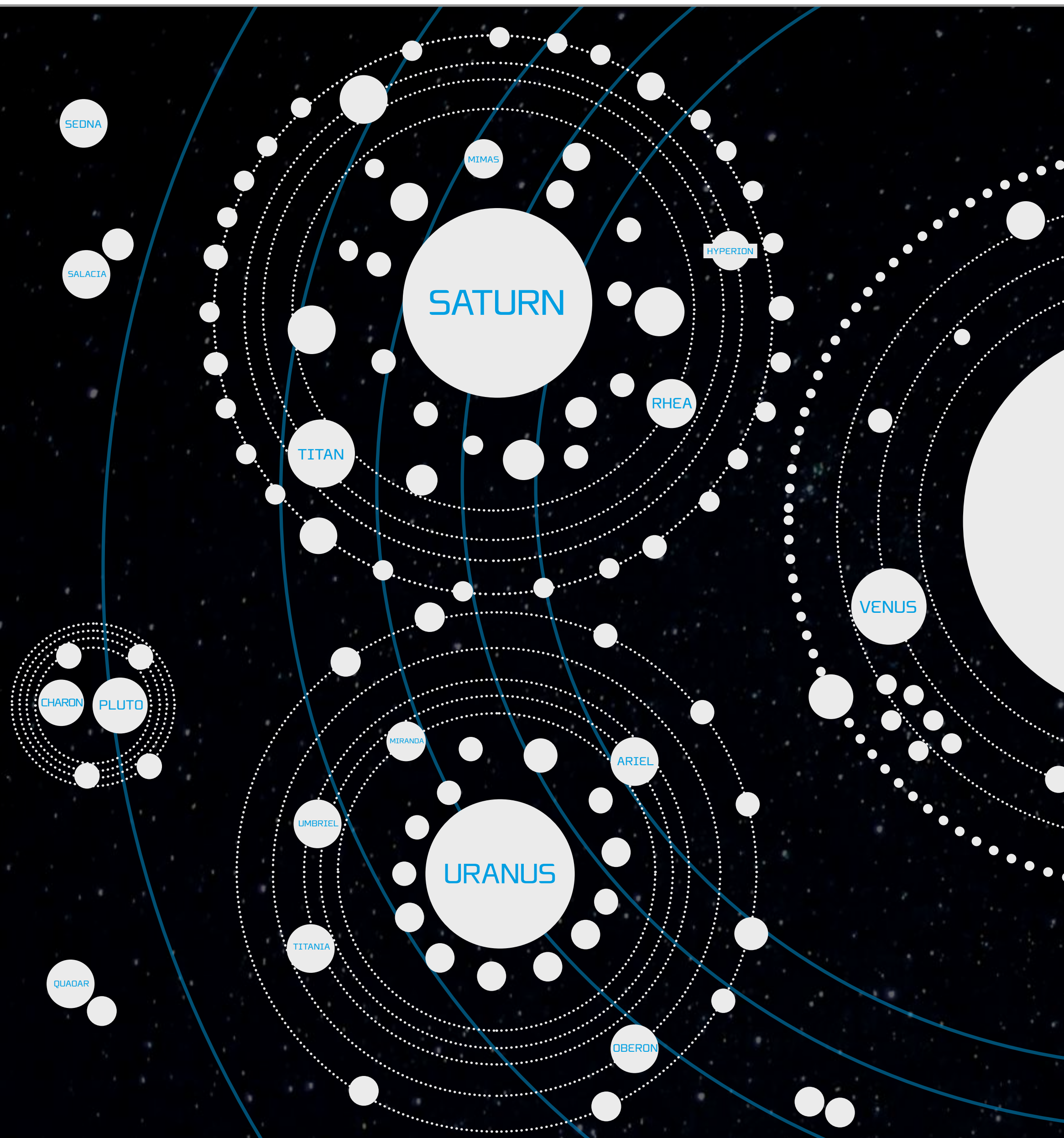
Although Pluto meets some full planetary criteria, such as its spherical body, which has been rounded by gravity, and the fact that it orbits the Sun, the problem with Pluto is that it hasn't cleared away its 'neighbourhood' of other objects. During and since its formation, Pluto didn't hoover up or eject other celestial bodies from its orbital path like its planetary superiors.



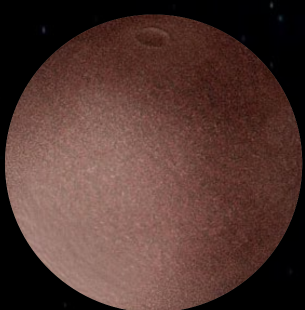
Pluto as imaged by the New Horizons spacecraft

CELESTIAL BODIES

DISCOVER SOME OF THE MANY DWARF PLANETS AND MOONS ORBITING IN OUR SOLAR SYSTEM



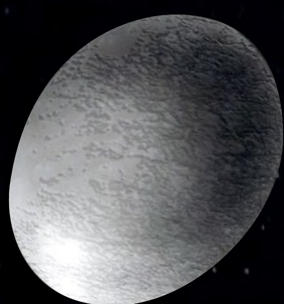
AR ZONE!
SCAN HERE



Makemake

Found around 4.2 billion miles from the Sun, just outside the orbit of Neptune, this dwarf planet is the second-brightest object in the Kuiper Belt – the first being Pluto. Its discovery in 2005 prompted the International Astronomical Union to form a new classification of celestial bodies, called dwarf planets.

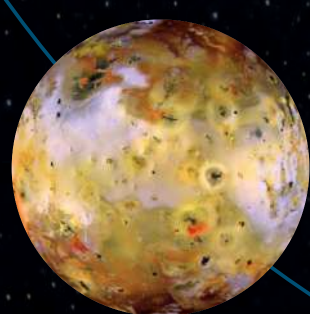
© NASA



Haumea

Haumea sits in the Kuiper Belt and is one of the fastest rotating large objects in the Solar System. A single day on Haumea is equivalent to four hours on Earth, but due to its proximity to the Sun, one Haumean year is equal to 285 Earth years. This oval-shaped dwarf planet also has two moons: Namaka and Hi'iaka.

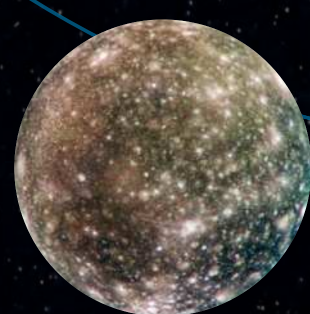
© NASA



Io

Io is one of the most volcanically active bodies in the Solar System. There are hundreds of volcanoes covering the moon's surface, each of them spewing lava dozens of miles high, along with lakes of molten silicate. It's thought that Jupiter's intense gravitational pull is the reason for Io's explosive nature.

© NASA/JPL

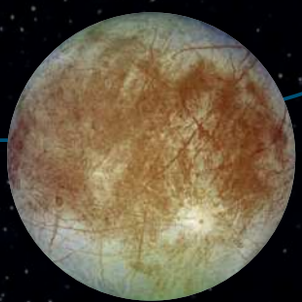


Callisto

Callisto has a circumference of 9,410 miles, which is almost as big as Mercury. Not only is this moon impressively large, it also has a salty secret deep below its icy surface. Discovered in 1610, it wasn't until the 1990s that scientists proposed the moon has a subsurface ocean about 155 miles below its surface.

© NASA/JPL/DLR

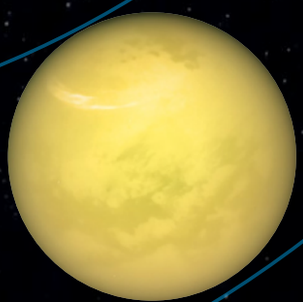
"Asteroids are leftover chunks of rock from when the Solar System formed"



Europa

Another of Jupiter's many moons, Europa is one of the oddest. With a surface temperature of around -160 degrees Celsius, this frozen satellite bears strange streaks. These markings are thought to be cracks in the moon's icy surface, which may have been caused by the tidal forces of an ocean deep beneath it.

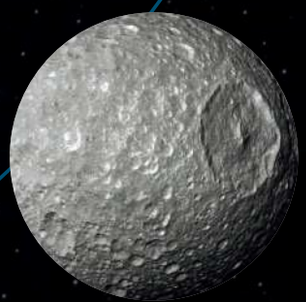
© NASA/JPL/DLR



Titan

Although the structure of Titan remains unclear, scientists think its core is made of rock around 2,500 miles in diameter, surrounded by layers of water ice. This satellite has a dense atmosphere, which gives it its yellow hue. The composition of this atmosphere is primarily nitrogen and some methane.

© NASA/JPL-Caltech/Space Science Institute



Mimas

Often called the Death Star moon for its similarity to the space station in *Star Wars*, Mimas is one of Saturn's smallest inner moons. Its iconic impact crater, named Herschel after English astronomer William Herschel, who discovered Mimas in 1789, spans 80 miles and reaches 3.5 miles high at its peak.

© NASA/JPL-Caltech/Space Science Institute

Hyperion

Not all moons are spherical. Some, like Saturn's sponge-like moon Hyperion, are irregular and filled with deep caverns. With a lower density than water, this moon is made up of water ice and likely frozen methane or carbon dioxide. Hyperion's appearance is thought to be the result of its distance from Saturn.

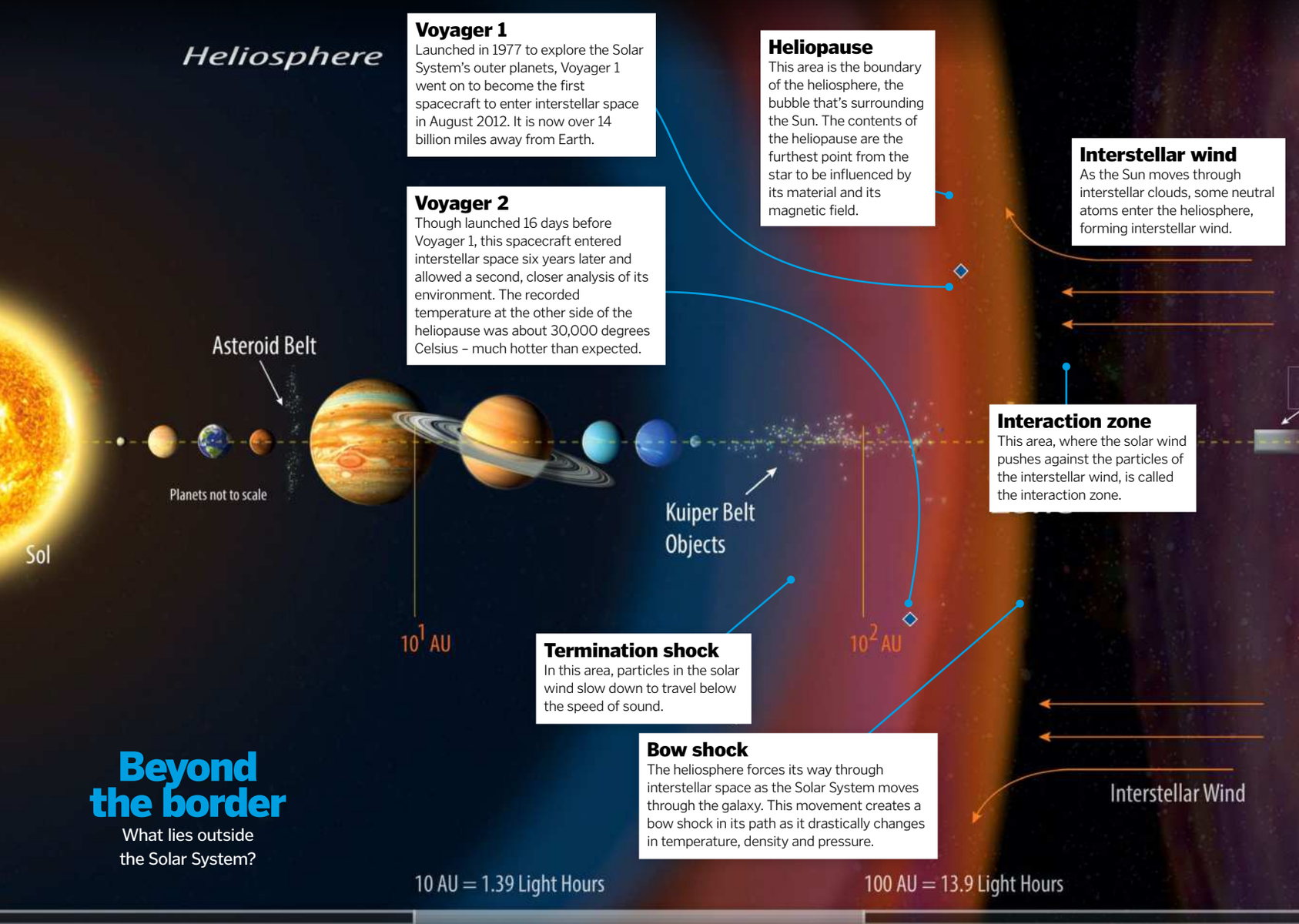
© NASA/JPL/Space Science Institute

What's in interstellar space?

The darkest regions of the galaxy birth the brightest stars

Despite being as close to a vacuum as can be achieved within our galaxy, interstellar space is far from empty. Beyond the Sun's surrounding bubble, which is created by the solar wind, interstellar space is defined as the region of space that is no longer impacted by the outflow of material from surrounding stars.

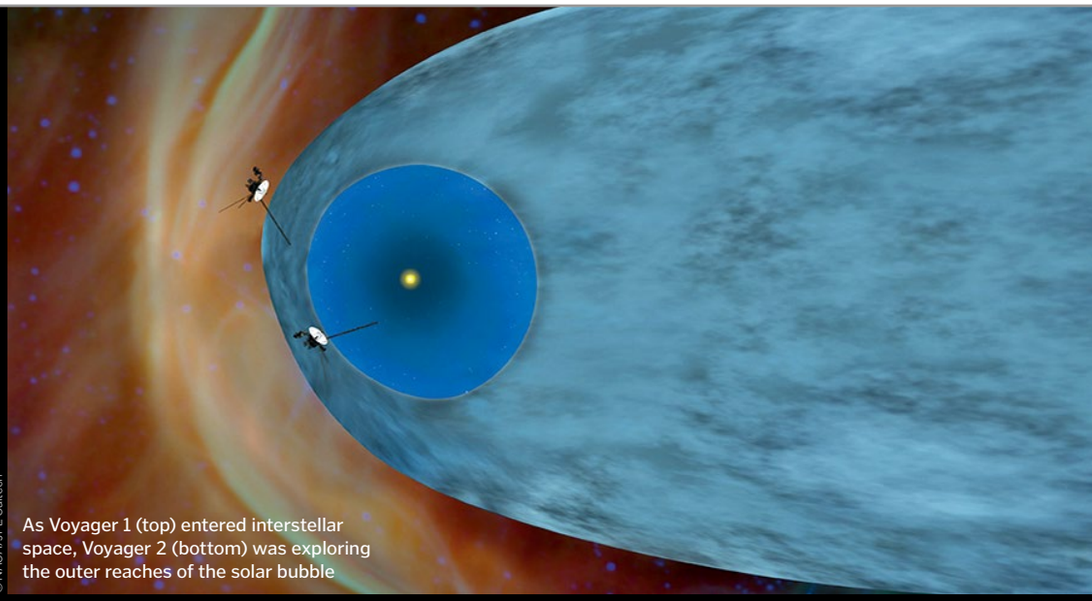
The environment between the galaxy's stars contains large clouds of gas – mainly made up of hydrogen and helium – and tiny dust particles. Its density can vary by location, but on average the medium contains just one atom per cubic centimetre. Mostly located at the outer arms of the Milky Way, where stars are more sparse, interstellar space makes up about five per cent of the galaxy's total mass.



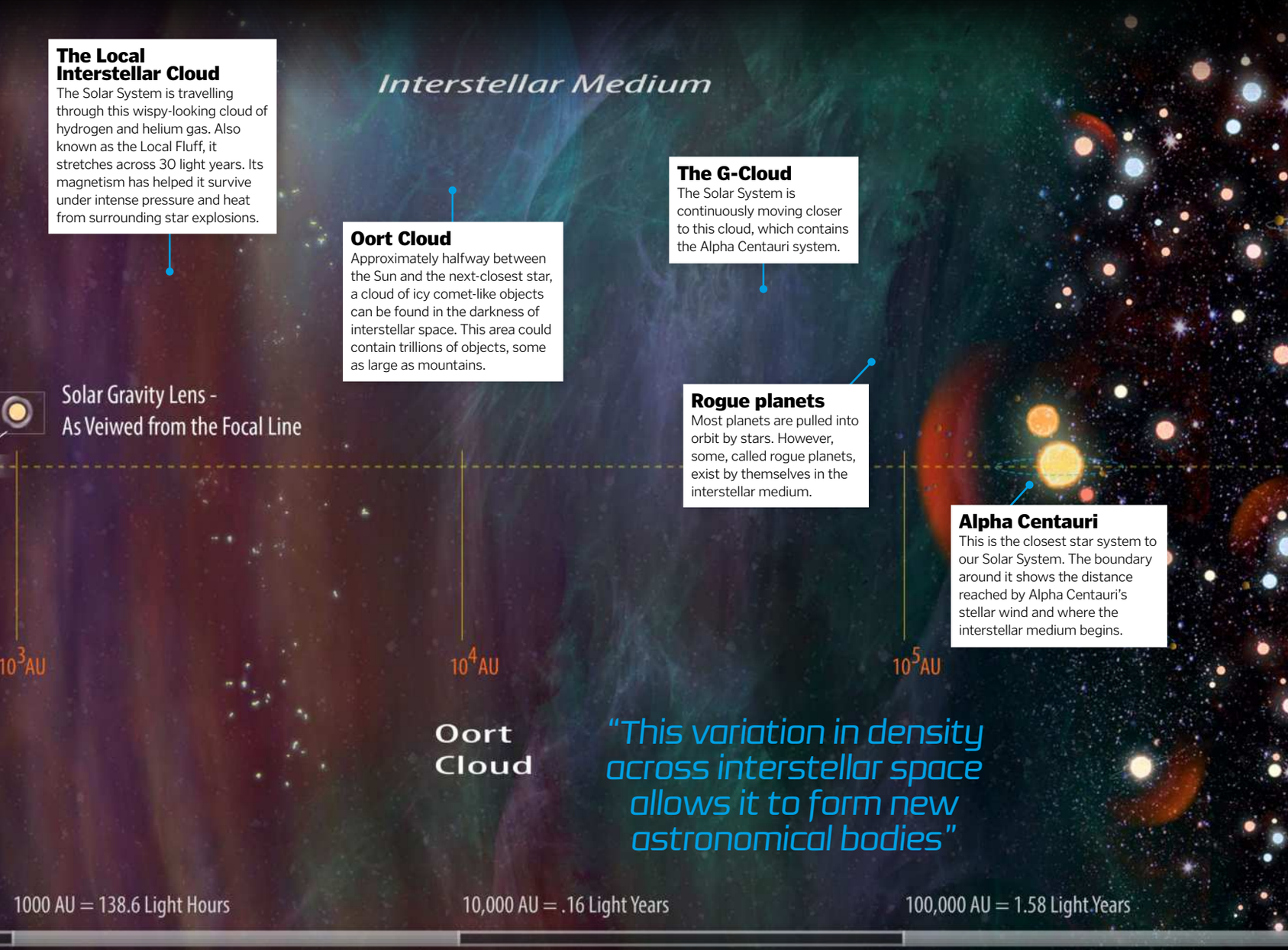
Beyond the border

What lies outside the Solar System?

When matter returns to the interstellar medium as a result of a star's death or being ejected into space from a star, it brings with it heavier elements such as iron and silicon. These elements are circulated by the gravity of surrounding stars, forming large, concentrated clouds that hold the potential to condense and form new stars. As this matter condenses, it forms molecular clouds – also known as stellar nurseries – where stars are born. It's this variation in density across interstellar space that allows it to form new astronomical bodies, like stars and the complex planetary systems we know today. We have the continuous evolution of the material between the stars to thank for our home world and our existence.



As Voyager 1 (top) entered interstellar space, Voyager 2 (bottom) was exploring the outer reaches of the solar bubble



THE HIDDEN UNIVERSE

DARK MATTER AND DARK ENERGY MAKE UP 95 PER CENT OF THE UNIVERSE, YET WE CAN'T SEE THEM. WHAT IS THIS STRANGE STUFF?

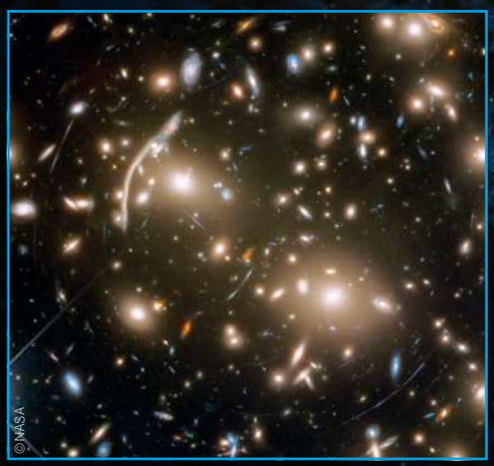
Words by **Andrew May**

As telescopes became increasingly powerful during the 20th century, they started to reveal the true scale of the cosmos. Astronomers discovered that there were billions of other galaxies like our own, scattered throughout a vast, continuously expanding universe. At the same time, advances were made in theoretical cosmology, stemming from Einstein's theory of general relativity, which showed in precise detail how objects move under the influence of gravity. When those two developments – observational and theoretical – were put together, researchers came to a startling conclusion. By the end of the 20th century, it was clear that all those billions of visible galaxies were just a small fraction of everything there is.

The hidden 95 per cent of the universe goes by the names dark matter and dark energy – but these are two very different things. The word dark is appropriate in the sense that we are 'in the dark' about them – we can't observe them directly, and we don't know what they are. But it's misleading to think of them as being dark in colour. That's true of something like cosmic dust, which we can see quite easily if it gets between us and a bright object that it partially obscures, but dark matter and dark energy are completely transparent. Light across all wavelengths, and all other matter, simply passes through them as if they weren't there.

Dark matter was discovered first – and the underlying theory is easier to understand. There's no need for relativity here, just Isaac Newton's basic theory of gravity. When you have a large ensemble of stars in a galaxy – or galaxies in a galaxy cluster – despite all the complex physics that's going on inside them, gravity is the only thing that determines their motion. Just as a spacecraft can attain 'escape velocity' from Earth orbit if it's moving fast enough, there's a maximum speed that stars can travel at – determined by the total amount of gravitating matter in the galaxy – before they fly off at a tangent. It turns out that the stars in the outer parts of most galaxies are moving too fast, at least if the visible matter was the only thing holding them in. The concept of dark matter, which supplies the missing gravity but is undetectable by any other means, is the simplest way to explain the observations.

Astronomers see evidence for dark matter everywhere they look – here in our own galaxy, and in other neighbouring galaxies.



A dense galaxy cluster interspersed with blue arcs, which are more distant, gravitationally lensed galaxies

The constituents of the universe

From observations of stellar and galactic motions, astronomers know the universe must contain around five times as much dark matter as ordinary visible matter. Adding dark energy to the picture is a little harder. It isn't made up of material particles, as dark matter presumably is, so we can't simply characterise its contribution as so many kilograms per cubic metre. But thanks to Einstein's theory of relativity, we know that energy is equivalent to mass, and cosmological observations allow us to work out the amount of dark energy in a way that is directly comparable to the other two. The result, according to NASA's latest estimate, is that the universe is 68 per cent dark energy, 27 per cent dark matter and just five per cent ordinary matter.

Relative proportions of dark energy and matter – the latter split further into 'ordinary' and 'dark'

In contrast, dark energy only becomes apparent when we take a wider view of the universe as a whole. For a century now we've known that the universe has been expanding ever since the Big Bang. It's common sense to assume that this expansion is gradually getting slower over time, pulled back by the combined gravity of all the matter in the universe. But in the 1990s astronomers discovered that the exact opposite is true: the expansion rate is actually accelerating, not slowing down. Something is counteracting the effect of gravity, pushing galaxies apart faster and faster. That 'something' – and no one knows what it is yet – has been dubbed dark energy.

One thing both dark matter and dark energy have in common is an absence of direct evidence. They're assumed to exist because they're the simplest way to reconcile observations with theory. But it's possible that theory and observations are wrong, and we don't really need dark matter or dark energy after all. But the indirect evidence for them is mounting up all the time, so most astronomers believe they're here to stay.

Dark matter

It was in the 1930s that Fritz Zwicky first noticed a discrepancy between the visual appearance of galaxies and the speeds they were travelling at. When studying the Coma galaxy cluster, he realised that in order for it to be held together by gravity, it had to contain far more mass than he could see. He coined the term 'dark matter' for the unseen contribution.

By the 1960s, spectroscopy had progressed to the point where high-resolution measurements could be made of stellar velocities inside a galaxy and plotted against radius. One of the great pioneers of these 'galactic rotation curves' was Vera Rubin. She discovered that the outer parts of most disc galaxies rotate much faster than would be expected from the gravitational effect of visible matter. The implication was that galaxies were embedded in a 'halo' of dark matter, the density of which dropped off more slowly with radius than that of the visible disc.

©ESO

Disc galaxies, like the Sculptor Galaxy shown here, are embedded in a halo of dark matter

Probing dark matter

Although it can't be seen, dark matter can be investigated using gravitational lensing

Light rays
Light from the distant galaxy doesn't travel in straight lines; it's bent by the gravity of dark matter.

Distant galaxy
This is a bright, distant object that we can see through a telescope.

Rays we see
These two light rays, following different routes, both reach the observer, who sees two images in different directions.

Intervening galaxy cluster
This cluster is closer to us and is dominated by dark matter, which we can't see.

Observer
An observer sees the distant galaxy and the intervening cluster, but not the dark matter.

Computer analysis
By comparing the distorted image of the galaxy with computer models, astronomers can map the distribution of intervening dark matter.

The accelerating universe

Dark energy is speeding up the expansion of the universe

The Big Bang
Occurring about 13.8 billion years ago, this was the start of the universe, which has been expanding ever since.

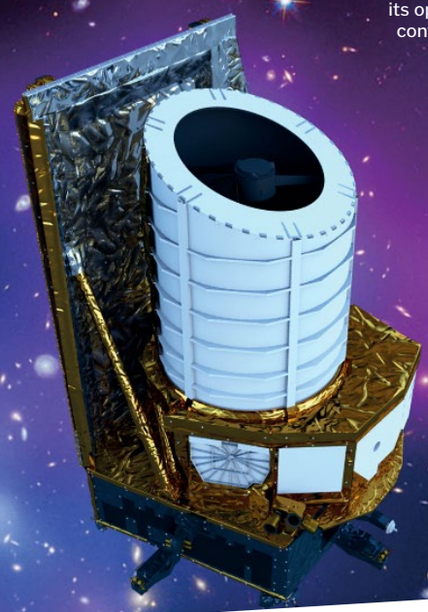
Decelerating expansion
As time went on, the force of gravity began to slow the expansion.

Rapid initial expansion
Soon after the Big Bang, the expansion rate was extremely rapid.

"Something is counteracting gravity, pushing galaxies apart faster and faster"

The Euclid mission

The European Space Agency's (ESA) Euclid space telescope, scheduled for launch next year, is designed to investigate both dark matter and dark energy. It will map gravitationally lensed galaxies, from which the distribution of intervening dark matter can be deduced. It will also study so-called 'baryonic acoustic oscillations', which are ancient patterns imprinted in the large-scale distribution of galaxies. Like explosive supernovae, these provide a standard ruler which allows astronomers to trace the expansion history of the universe – including the acceleration caused by dark energy. In a mission lasting six years, Euclid will survey galaxies in visible and infrared wavebands over an area of sky covering more than 35 per cent of the celestial sphere.



An artist's impression of the Euclid spacecraft in its operational configuration

© ESA

Dark energy

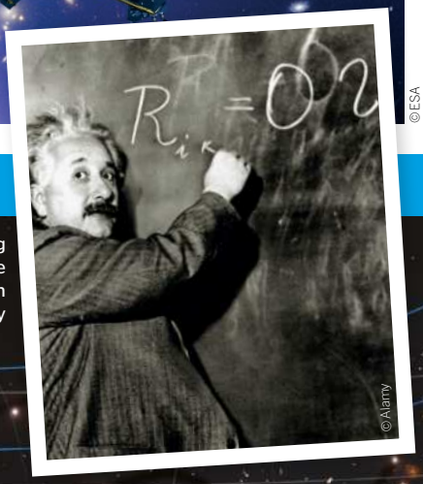
Astronomers accidentally discovered dark energy when they were looking for something else. They wanted to calculate the total mass of the universe by measuring the rate at which its gravitational pull slowed down the expansion rate. They attempted to do this by graphing recession speed versus distance for a special class of astronomical objects called Type Ia supernovae, but the result wasn't what they expected. The expansion of the universe isn't slowing down at all – in fact, it's speeding up.

It's as though the universe is filled with a mysterious something – dark energy – that counteracts the pull of gravity on the largest scales and pushes even harder in the opposite direction. This discovery was in a different league from dark matter, which may be a completely unknown substance, but at least obeys the laws of Newton and Einstein. Dark energy, with its strange, antigravity-like behaviour, doesn't even do that.

Or perhaps it does, if we look at an obscure factor in Einstein's equation called the cosmological constant. It has no counterpart in Newton's theory, and for years was assumed to be zero. But if it has a small positive value, it could explain dark energy as a fundamental property of space itself.

© Getty

Brian Schmidt, Saul Perlmutter and Adam Riess, whose supernovae measurements showed that dark energy exists



© Alamy

Einstein included something similar to dark energy – the cosmological constant – in his theory of relativity

Dark energy kicks in

Around 5 billion years ago, dark energy started to affect expansion, which began to speed up again.

The present

The rate of expansion is still accelerating, so the universe is larger than it would have been without dark energy.

The future

Scientists think that dark energy will become increasingly dominant, with galaxies eventually becoming extremely far apart.

AR ZONE! SCAN HERE

The Solar System's outer limits

Thanks to recent discoveries, we now have a clearer picture of what lies beyond Pluto

Words by **Andrew May**

For 60 years after its discovery in 1930, Pluto – together with its largest moon Charon, discovered in 1978 – marked the outermost limit of the Solar System. With an average distance from the Sun of 39 astronomical units (AU) – with one AU the distance from Earth to the Sun – that's pretty far out. But the 1990s saw the discovery of numerous other 'trans-Neptunian objects' beyond the orbit of Neptune, the most distant of the major planets, 30 AU from the Sun, with further discoveries coming in ever since.

Pluto actually resides in a relatively populous neighbourhood called the Kuiper Belt – a doughnut-shaped region extending from around 30 to 50 AU which contains hundreds of thousands of bodies larger than 62 miles in size.

Pluto is still the largest Kuiper Belt object (KBO) we know of. With a diameter of 1,473 miles, it has enough gravity to pull it into a spherical shape, classifying it as a 'dwarf planet' – a status it shares with other large KBOs such as Makemake and Haumea.

Smaller KBOs are more irregular-looking, resembling the asteroids found closer to the Sun. Unlike asteroids, however, which tend to be rocky in composition, KBOs are predominantly made of water ice and frozen methane and ammonia.

The region beyond the Kuiper Belt, called the 'scattered disc', contains icy bodies that have been scattered by Neptune's gravity into highly eccentric orbits. These may stray hundreds of AU from the Sun, rising far above the central plane, before their orbits take them back almost to the orbit of Neptune.

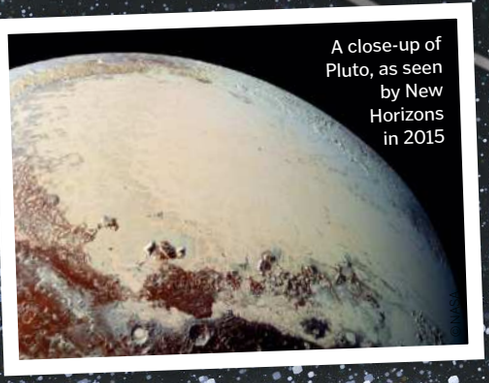
The largest scattered-disc object discovered so far, Eris, is similar in size to Pluto. In the course of its 557-year orbit, it roams all the way from inside Pluto's orbit to almost 100 AU from the Sun.

The outer Solar System

Trans-Neptunian space is filled with objects, including dwarf planets, which are fascinating worlds

Kuiper Belt
Stretching from around 30 to 50 AU, this is home to hundreds of thousands of small icy bodies.

Eris
Another dwarf planet and similar in size to Pluto, Eris is the largest known object in the scattered disc.



A close-up of Pluto, as seen by New Horizons in 2015

A brief history of distant worlds

In a sense KBOs have been known since antiquity – gravitational interactions can send them hurtling into the inner Solar System, where we see them as comets.

Astronomer Gerald Kuiper – after whom the belt is named – proposed such a scenario in the 1950s, but it wasn't until the 1990s that powerful telescopes began discovering KBOs in-situ in the outer Solar System. Astronomers were surprised to find that several of these were comparable in size to Pluto, which had hitherto been classified as a planet, playing a part in its demotion.

© NASA

Many comets, including Halley's Comet seen here, originate in the Kuiper Belt

New Horizons

The first and so far only spacecraft to explore the Kuiper Belt, NASA's New Horizons was launched in January 2006 and reached its first destination, the Pluto system, in July 2015. Passing within 7,767 miles of Pluto and 17,895 miles of Charon, the probe succeeded in capturing breathtaking images of both worlds. It also sent back masses of scientific data, including detailed maps of chemical composition and surface temperature.

Although Pluto was its main goal, New Horizons was designed to remain operational afterwards, using long-range sensors to investigate other KBOs. It had its second close encounter on 1 January 2019, this time with a recently discovered KBO just 21 miles across, which has since been named Arrokoth. Even that wasn't the end of the mission, and New Horizons is still going strong, passing the 50 AU milestone – 50 times farther from the Sun than Earth is – in April 2021.

5 FACTS ABOUT DISTANT OBJECTS

1 Total mass
Although there are hundreds of thousands of Kuiper Belt objects, NASA estimates their total mass to be no more than a tenth that of Earth's.

2 Planet 9?
Peculiarities in the orbits of some KBOs have led to speculation that there is another large planet way out beyond Neptune – but it isn't likely, and there are other explanations for this.

3 Seven light hours
At its current distance of 50 AU, it takes radio signals seven hours to reach New Horizons – and another seven for the answer to come back.

4 Farfarout
The most distant object discovered in the Solar System is a dwarf planet 132 AU from the Sun. First observed in 2018, it's been given the nickname Farfarout.

5 Oort Cloud
Hypothesised to exist far beyond the Kuiper Belt, the Oort Cloud is a roughly spherical shell of comet-like objects extending from around 2,000 to 100,000 AU from the Sun.

Pluto and Charon
The best-known dwarf planet in the Kuiper Belt, Pluto actually forms a binary system with its largest moon Charon.

Sedna
Also in the scattered disc, Sedna is currently 85 AU away, but its orbit extends to almost 1,000 AU.

Haumea
Part of the Kuiper Belt, dwarf planet Haumea has a distinctive oval shape, caused by its rapid rotation.

"Pluto resides in a relatively populous neighbourhood"

Scattered disc
Extending hundreds of AU beyond the Kuiper Belt, objects in this region generally move on more eccentric, highly inclined orbits.

ENVIRONMENT

074
Sea monsters

066
Hurricane power
AR ZONE!

HURRI

HURRICANE POWER

HOW THE OCEAN CONCOCTS EARTH'S MOST VIOLENT STORMS – AND HOW WE'RE ABLE TO FLY RIGHT INTO THEM

Words by **Ailsa Harvey**

If the weather symbolised its emotions, Earth would have some dramatic mood swings. Over the course of a spring day in temperate parts of the world you can be exposed to illuminating sunshine, pouring rain and a torrent of hail as the weather changes its mind. But these changes are insignificant when compared to the violent outbursts that erupt from the middle of the planet's vast oceans.

In fact, the ocean could be considered the moodiest location on Earth, with its frenzied waves colliding at the surface, extreme currents pulling underneath and relentless gales rushing over the top. Covering the majority of the planet, this extensive body of water can move with mesmerising power.

Hurricanes are storms of tremendous size and wind speeds with the power to do devestating damage. Nothing living can outrun a hurricane, not even a cheetah – the world's fastest land animal. They're brought into existence by the connection between the ocean and the atmosphere. These swirling giants are formed from built-up pressure, where warm water is lifted from the ocean's surface and into the atmosphere to become an unstoppable force of spinning air. These massive storms have been known to reach sizes over 2,000 kilometres in diameter as they surge across water and land, displacing anything and everything in their path.

Hurricanes are an undeniable threat to humans because they are one of the rare products of Earth we have no control over. For those who

DID YOU KNOW?

19 million

trees were knocked down by Hurricane Floyd

have witnessed their destruction firsthand, it can't be denied that they have the power to ruin lives.

Yet we still look at this power in awe. These enormous, whirling systems are concocted from natural forces alone. They occur spontaneously and maintain their astonishing peak force for many days at a time. As if armed for an attack on the land, they move with the wind while firing their weapons: wipeout waves, flooding rain and gusts of wind that put human-made shows of strength to shame.

Nature holds the ultimate power, whether that is used to destroy or to create. Looking past the ruinous aftermath that follows a hurricane, their path can also display some benefits to the environment. Moving in a rotating pattern around a calm centre, these storms help to maintain a global heat balance across the planet, without which the poles and tropics would have much more extreme temperatures.

There is already a stark difference between these areas, and with almost all hurricanes moving outwards from the equator, tropical storms channel heat energy effectively to colder waters.

A hurricane's job as an agent of dispersal doesn't end at sea. If their winds can make uprooting the thickest trees look effortless, imagine how easy it is for them to carry tiny, lightweight seeds that have evolved to harness the wind. With speeds and power unlike the gusts and breezes that many plants use to disperse seeds, hurricanes can spread plant species much further than the wind would. In some cases they have even brought distant areas destroyed by fires and other environmental disasters back to life.

Today we know more about hurricanes than we ever have, making the prediction of their emergence and their potential paths much easier. The importance of this lies not only in increased knowledge, but in warning communities and saving lives. So how can a hurricane be spotted in advance?

The National Hurricane Center (NHC) is responsible for overseeing tropical storm escalation, aiming to spot hurricanes 48 hours before they reach land. This might sound like something of a guessing game, but with the evolution of more advanced technology this process is made easier.

Satellites have become a main source for obtaining this information. Being further away from the storm allows the technology to analyse the activity more closely with a variety of sensors. Radars are used to track rain and wind speeds, while infrared sensors can monitor temperature differences within growing storms and help to locate their centres.

Once the whereabouts of volatile atmospheres are determined, aircraft can take a closer look, equipped with the tools to measure the intensity and direction of increasing winds. Down on Earth, ground stations, sea buoys and ships analyse areas where hurricanes are born.

Ocean buoys float at the surface of the water at common hurricane-forming sites. Moving with the waves and currents, they can measure wave height, swell direction and the surrounding wind, air and water temperatures and pressures. When changes in these conditions begin to turn towards those ideal for a hurricane birth, meteorological centres can be alerted.

Being given this wide array of information, forecasters need to put together a likely picture by feeding all this data into a superfast computer. But although scientists know what conditions are needed to form a hurricane, they don't know why one doesn't occur every time the conditions are right. For this reason the activity within the ocean and atmosphere has to be closely monitored. As soon as tropical storms begin to accelerate towards Category 1 speeds, they use global wind patterns to plot the potentially impacted land mass. Drawing out multiple path possibilities, populations which could be affected can be warned in advance.

These awesome forces of nature can usually be observed between June and November, with hurricane season peaking between August and October. It is impossible to put up a fight against these power-accumulating wind towers, so the best thing to do is give them right of way and stay clear of their predicted paths. Evidence shows that recent hurricanes are intensifying more quickly in the last few years, so watch out the next time nature kicks up a storm.

What's in a name?

Each hurricane has unique qualities, forges its own path and carries varying levels of destruction, so a method to differentiate between them is needed. The US began using short, memorable names in 1953 to avoid confusion between storms and to communicate their danger quickly. The World Meteorological Organization controls the naming using the following procedure.

There are six lists of names. They alternate between male and female and contain all the letters of the English alphabet minus Q, U, X, Y and Z. This removes any difficulty in name pronunciation. Each list from A to W is followed each year, and if there happen to be more hurricanes than letters in a season, the names move on to the Greek alphabet.

© Getty

Before the World Meteorological Organization was founded, hurricanes were given numbers


© Getty

A hurricane is more than capable of tearing a house to pieces

DID YOU KNOW?

8,000 deaths

The deadliest hurricane took place in 1900

RATING NATURAL POWER

ESSENTIAL INGREDIENTS

These components are vital for the formation of these intense storms

Weather disturbance

Hurricanes develop from previous weather disturbances. A tropical storm begins as an area of low atmospheric pressure.

Warm water

The ocean needs to be at least 26.5 degrees Celsius, covering depths of 50 metres.

Thunderstorm

Thunderstorms are built into something larger, stronger and more explosive.

Wind

Air needs to travel vertically from the ocean, creating a lifting mechanism.

CATEGORY 1

119 to 153kph

Although it's the lowest category, danger can be displayed in falling debris and the destruction of older mobile homes. Protected glass windows are likely to survive intact, but snapped power lines can leave impacted areas in darkness.

CATEGORY 2

154 to 177kph

This category puts all mobile homes under threat and the increased strength brings higher likelihood of injury and death. Power losses should be expected.

CATEGORY 3

178 to 208kph

Risk of injury and death becomes high. Many houses and flats are subjected to significant damage and the storm tears trees from the ground. Affected areas can have to live without water and electricity for weeks.

CATEGORY 4

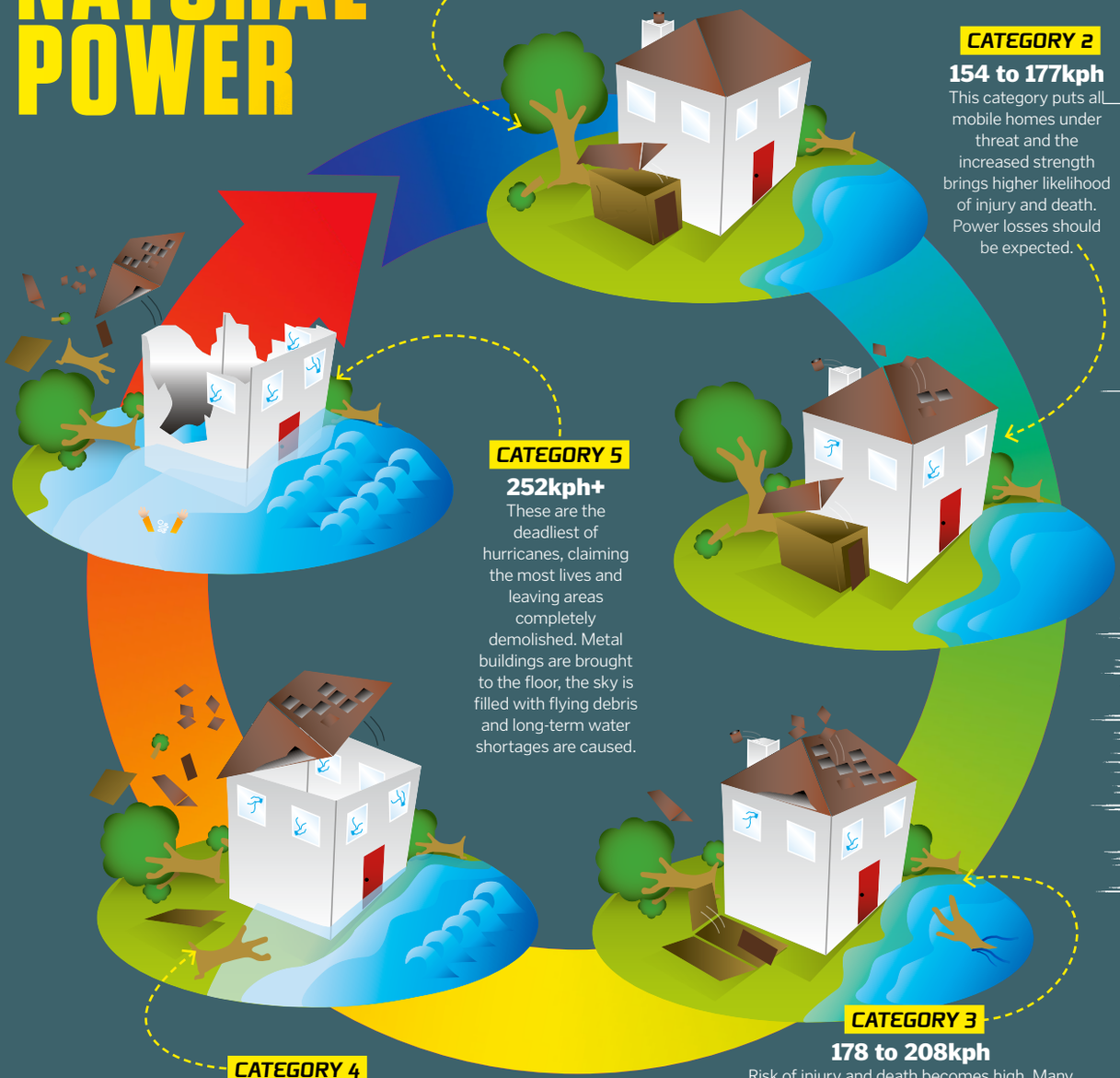
209 to 251kph

The risk to life is now very high. Hurricanes in this category will break most windows in high-rise buildings and blow the roofs off houses. Power damage and water shortages mean areas can become impossible to live in, sometimes for months.

CATEGORY 5

252kph+

These are the deadliest of hurricanes, claiming the most lives and leaving areas completely demolished. Metal buildings are brought to the floor, the sky is filled with flying debris and long-term water shortages are caused.



DID YOU KNOW?

2005

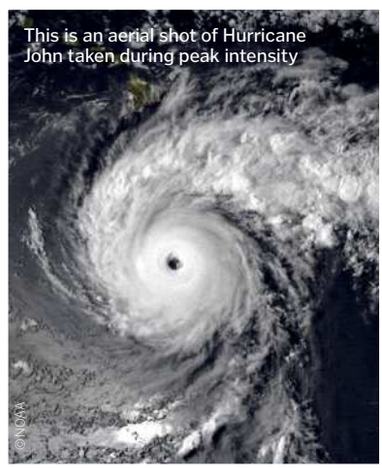
This was the most active Atlantic hurricane season on record, with 27 named storms

Where are they found?

Ocean water closest to the equator is the warmest because it's more exposed to direct solar radiation. Because this warmth is required to begin the movement of air particles, it is close to this central line where tropical storms usually brew.

Hurricanes, cyclones and typhoons all form along this line, but what makes them different from each other? The answer is nothing. These are simply three titles for the same weather pattern, given a variation in name depending on the region where they form.

Once in action, the route taken by these violent bursts and the time the storms last can be diverse. Their paths are steered by global winds and their life span depends on strength and access to fuelling resources along their path. While an average hurricane will last for several days, Hurricane John sustained its power for 31 days in 1994.



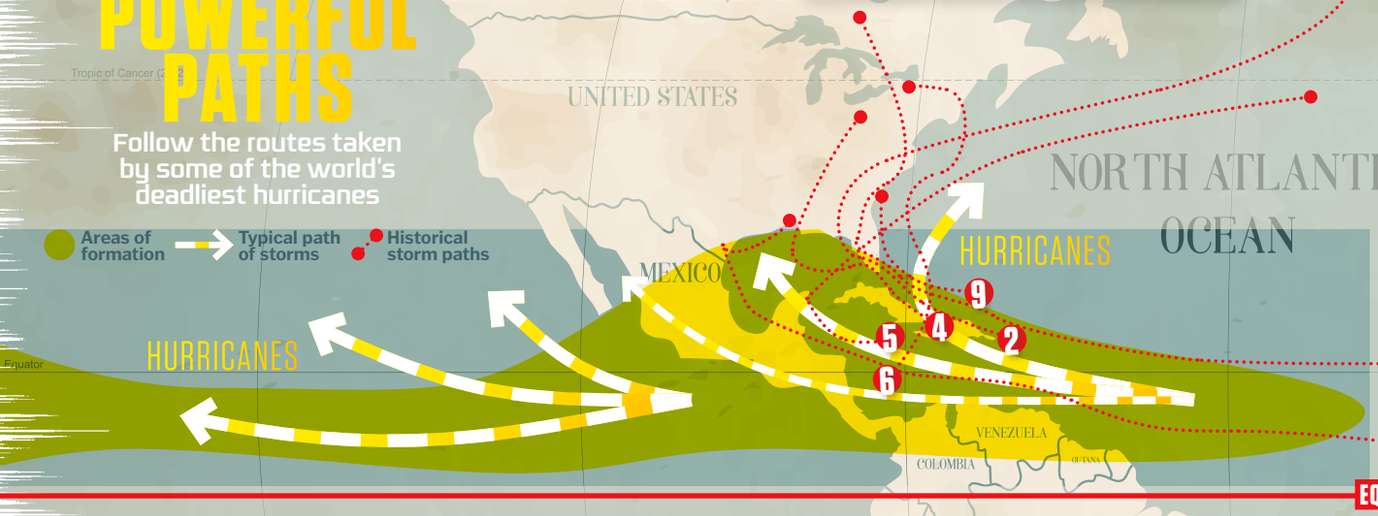
This is an aerial shot of Hurricane John taken during peak intensity

9 Dorian
The aftermath of Dorian is shown here after its route through Marsh Harbour in the Bahamas, 10 September 2019.

© Getty

POWERFUL PATHS

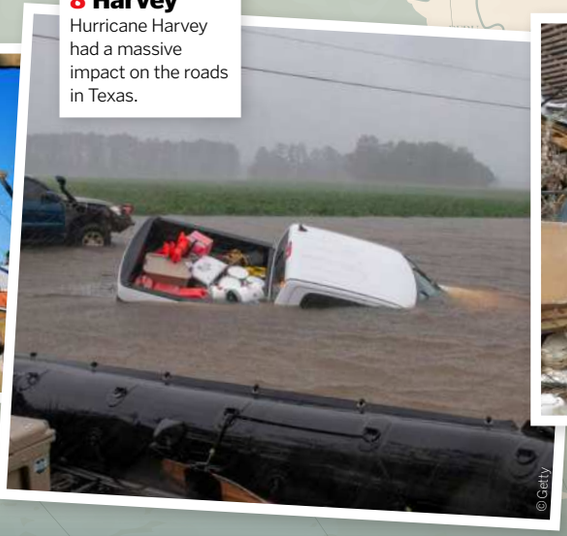
Follow the routes taken by some of the world's deadliest hurricanes



EQUATOR

© Getty

7 Haiyan
This is what the houses in the city of Iloilo looked like after Typhoon Haiyan.



© Getty

8 Harvey
Hurricane Harvey had a massive impact on the roads in Texas.

© Daniel Lobo

4 Katrina
A pile of debris shows the strength of Hurricane Katrina in Mississippi.

HURRICANES THROUGH HISTORY

1 Okeechobee
Date: **6-21 September 1928**
Category: ●●●●●
Deaths: **4,000+**

Okeechobee made landfall near West Palm Beach, Florida, late on 16 September, tearing up the land and homes and taking lives. Days before the hurricane had already claimed the lives of about 1,500 people in the Caribbean. The worst impacted area on the mainland was Lake Okeechobee, which gives the hurricane its name. This region was used primarily for farming, and although a small dyke had been built to protect the land, it was no match for Okeechobee's 225-kilometre-per-hour winds. Many workers were drowned in the flooded fields, caused by a storm surge.

2 Labor Day Hurricane
Date: **29 August - 10 September 1935**
Category: ●●●●●
Deaths: **485**

One reason why this hurricane cost the lives of hundreds is due to the underestimation of its scale. Hitting Florida Keys on 2 September, the hurricane obliterated the coast, where World War I veterans had been sent to build roads and bridges. 250 of them died doing this work because the organisers were unaware of the intensity of the incoming storm. Slamming into a 64-kilometre section of the coast, almost all human-made structures were ripped apart and the workers stood no chance in the fight for their lives. At the time it was the most intense hurricane to hit the US.

3 Bhola cyclone
Date: **3-13 November 1970**
Category: **Cyclone**
Deaths: **500,000+**

This tropical storm is a cyclone, which forms over the South Pacific and Indian Oceans. Bhola was one which caused severe havoc in both India and Bangladesh, then named East Pakistan. Those living on the coast had no idea of what was to come as meteorologists had no way of communicating with most living in the area. As they slept the cyclone crossed the land, carrying a wave of water six metres high and winds of over 225 kilometres per hour. Bhola is one of the deadliest natural disasters in recent history.

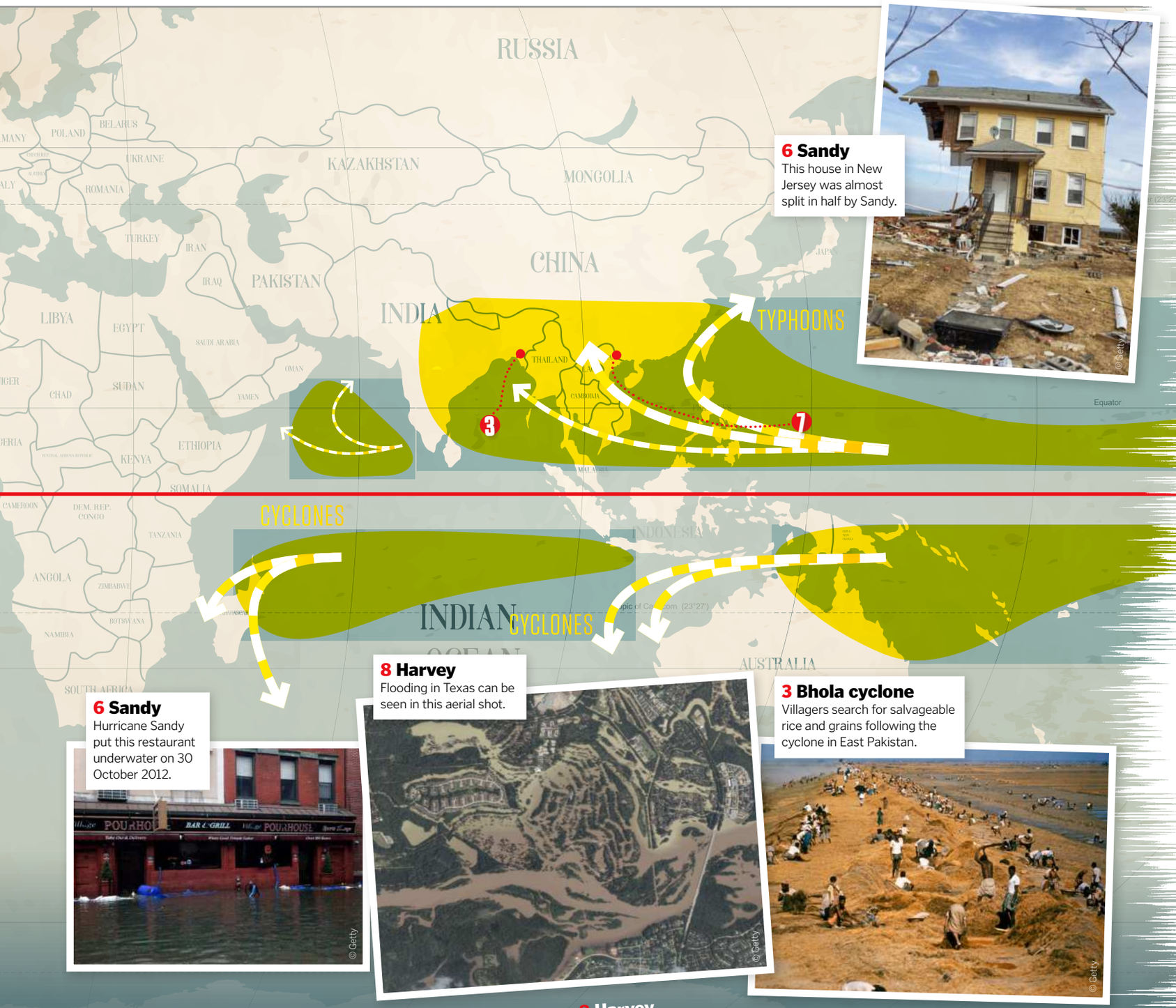
4 Katrina
Date: **23-31 August 2005**
Category: ●●●●●
Deaths: **1,800+**

When Katrina reached land in Louisiana, it was at Category 3, but it grew to a width which could reach across the entire Gulf of Mexico. Impacting great stretches of land, signs of Katrina's presence remained for over a decade. Criticising the preparation in place for such a storm, the search and rescue response and following action, Barack Obama said: "What started out as a natural disaster became a man-made disaster... a failure of government to look out for its own citizens."

5 Wilma
Date: **15-27 October 2005**
Category: ●●●●●
Deaths: **87**

Within 24 hours of becoming a hurricane near Jamaica, Wilma developed into a rapid Category 5, crossing two peninsulas. These were Mexico's Yucatán Peninsula, where some towns were flooded by rainfall of over one-and-a-half metres, and Florida, which it crossed in just four-and-a-half hours. In this limited time 6 million residents in Florida lost electricity for two weeks, while damage to sugar cane and other crops due to flooding made the hurricane one of the most expensive.

DID YOU KNOW? *Hurricanes that form north of the equator spin anti-clockwise, while southern ones spin clockwise*



6 Sandy
This house in New Jersey was almost split in half by Sandy.

6 Sandy
Hurricane Sandy put this restaurant underwater on 30 October 2012.

8 Harvey
Flooding in Texas can be seen in this aerial shot.

3 Bhola cyclone
Villagers search for salvageable rice and grains following the cyclone in East Pakistan.

6 Sandy

Date: **22 October - 2 November 2012**
Category: ●●●○○
Deaths: **285**

As it raged into mainland America, the hurricane became trapped by another storm. Having another nearby high-pressure storm meant that Sandy was unable to leave New Jersey and Delaware. As the two storms merged and became trapped along the coast, the increased scale of the affected area and persistence of the brutal winds rendered many people homeless – if they managed to survive.

7 Typhoon Haiyan

Date: **3 - 11 November 2013**
Category: **Super typhoon**
Deaths: **7,000+**

Targeting the islands of the Philippines, Haiyan is one of the strongest typhoons ever recorded. Subjecting the islands to seven-metre-high waves and relentless rainfall, the storm had a severe impact on the country's economy and killed people in devastating numbers. Of those who were lucky enough to walk away from the event, 1.9 million were left homeless. Not only does this storm highlight the impact on people's lives, it also shows how they can tear apart the environment. The uprooting of thousands of trees meant there was a significant loss in habitat for wildlife, creating a decline in biodiversity.

DID YOU KNOW?
13,280km
Hurricane John travelled a distance greater than the diameter of Earth

8 Harvey

Date: **17 August - 2 September 2017**
Category: ●●●●○
Deaths: **68**

Having made a pit stop in the Gulf of Mexico, Hurricane Harvey was ready to attack Texas with its power. It had just refuelled in the deep, warm water and would soon show off its newfound strength. While it was in the second-strongest category as it made landfall, the hurricane soon weakened, staying in one place for a prolonged period. As a result the total death toll is much lower than some of the other Category 4 hurricanes that came before it. What it didn't take in lives, however, it made up for in land. The mass flooding which came with the hovering hurricane destroyed the homes of 135,000 people in the area.

9 Dorian

Date: **24 August - 10 September 2019**
Category: ●●●●●
Deaths: **84**

Although classed as the slowest moving major hurricane on record, Dorian was one of the most catastrophic. Spending much of its progression above water, it was able to sustain a relatively long life span. Unfortunately for those in the Bahamas at the time, the route it took happened to trace the islands. Not only was this a lingering storm, but it is the strongest hurricane to have hit the Bahamas and one of the strongest across the entire Atlantic.

DID YOU KNOW?
90%
of hurricane deaths are due to flooding

INSIDE A HURRICANE HUNTER

Discover the planes collecting storm statistics and the people who risk their lives to get them

Pilot
Hurricane hunter pilots are in control. They undergo extensive training beforehand to enter the world's worst storms over and over again.

Co-pilot
The co-pilot is in continuous communication with the pilot throughout the flight. These details are also relayed to a flight engineer.

Flight director
At one of the closest stations to the cockpit, the chief meteorologist directs the flight path using incoming radar information. Their role is to ensure the mission objectives are met while the crew remains safe.

Navigator
The navigator tracks the storm's movements and determines the best route and approach.

Rain radars
Radars on the tail and belly of the plane provide information about rainfall density and turbulence. Multiple radars around the plane give a 3D perspective of conditions.

Engine power
Four powerful turbine engines ensure safe flying into extreme wind. There are two on each wing, but only two need to be running for safe flying. When needed, the extras can be used to keep the aircraft in control.

Probe dropping
These devices are sent outside the plane to further explore external conditions. Hurricane hunters carry two varieties; one drops straight to the ocean to measure water temperatures, while others provide data about air pressure, humidity, wind speed and direction.

AR ZONE! SCAN HERE

1 Probe parachute
Parachutes allow for a slower fall, giving time for the probe to collect data. It takes seven minutes for the probe to fall from six kilometres.

2 GPS antenna
Data from GPS satellites is collected to calculate wind speed and direction.

3 Microprocessor
This tiny device takes the data from the sensors and digitises them.

4 Radio transmitter
Every 0.5 seconds, this sends temperature, humidity, pressure and wind data back to the plane's computers.

5 Into the eye
The plane makes its first flight through the centre of the hurricane. Passing through the walls of the eye is the windiest and bumpiest section. It is here that the probes are dropped.

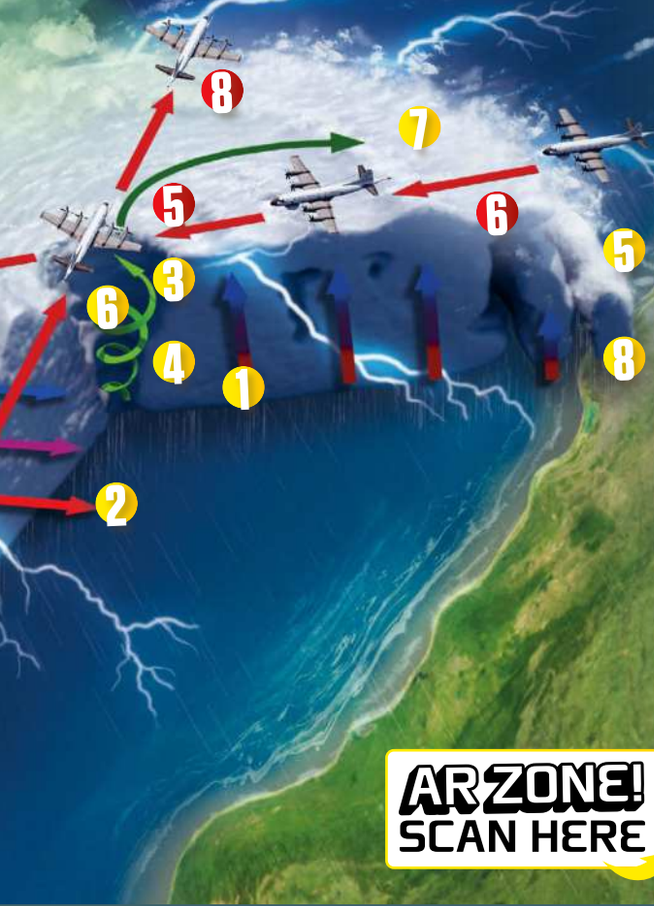
6 First crossing
After crossing through the entire hurricane, researchers on board have a good understanding of the conditions throughout.

DID YOU KNOW?

$160 billion

Hurricane Katrina made landfall in 2005 and remains the costliest hurricane in US history

Radar system
Doppler radars bounce microwaves off the inside of the hurricane. The data returned can show the speed of the wind.



AR ZONE! SCAN HERE

7 Crisscross
The plane takes its position to cross through the storm for a second time. Hurricanes can evolve so quickly that it may seem like an entirely different storm upon second entry.

8 End of route
The more the plane journeys into the storm, the more data will be collected. This route can sometimes be endured several times.

HOW HURRICANES FORM

A combination of forces create these mighty spectacles

1 Moist air
Hurricanes only form over warm waters. As the moist air is heated by the ocean it rises away from the water and pressure builds just above the surface. This warm air is the storm's fuel.

2 Begin to spin
To replace the rising air, surrounding particles move into the gap left behind. These then warm and rise, creating a cycle of particle movement. This ongoing displacement of air moves in a spinning motion.

3 Whirling winds
As wind increases, moving air particles in the centre push into the spiralling wind. With nowhere else to travel, this forces the air to move upwards at the centre.

4 Creating clouds
Having risen, the air is cooled and begins to form clouds where thunderstorms can take place.

5 Growing system
As air continues to rise and cool, the cloud and wind system continues to expand and spin.

6 Descending air
The storm gains speed and an eye forms at its centre. This clear section has a low pressure and forces high-pressure air from above it down into the massive central space.

7 Classification
Speeds progressively increase. When they reach 119 kilometres per hour, a hurricane is born.

8 Land limit
When travelling across land, the moisture and heat fuelling the hurricane stop the upward flow. The hurricane will continue to move over land until it loses energy.

DID YOU KNOW?

252kph

The most powerful hurricanes have winds with speeds the same as a free-falling skydiver

Storm chasers

While most people warned of a hurricane's approach plan their escape, some people don't run. It is their job to put themselves at the centre of these storms. One of the essential methods used to collect hurricane data is to fly straight into a storm. Unsurprisingly, being at the centre of a Category 5 hurricane isn't the safest place to find yourself. However, the planes used are specially designed for smooth flying under the stress of one of Earth's most unforgiving forces.

You might expect the strongest hurricanes to present the most challenges, but crews on these planes have said otherwise. It's actually the unpredictability of the ever-changing conditions that create sudden danger.

This photo was taken from inside the eye of Hurricane Floyd

Surfing the storms

While most adhere to precautionary measures and prioritise their safety, some people travel towards the shore, ready to take on what the storm has to offer. In this case the offering is big waves, and for many surfers this is the ultimate challenge.

Hurricane-generated swells are rare, more dangerous and everything these thrill-seekers crave. The towering waves are generated at the centre of storms. As water rises from the eye of the storm, it mixes with the high winds and currents, creating a surge of water. The closer the hurricane gets to land, the wilder the waves.

A surfer rides waves caused by Hurricane Rosa in 2018

SEA MONSTERS

What makes these animals some of the world's deadliest underwater hunters?

Words by **Ailsa Harvey**

Beneath the waves, millions of battles are taking place. Each sea-dwelling soldier uses their unique features to their advantage, with no two playing an identical game. In the diverse underwater world, an easy meal for one species could be another's biggest threat.

From the ocean's shallow shores to its dusky depths, over 200,000 different species dwell. For the majority of these animals, each day holds the possibility of being their last. They could be eaten at any moment, even while searching for their own food. Whether it's a whale using its sheer size as its weapon, or the refined tactics that help smaller species conquer, the sea is full of expert hunters.

How can an animal avoid doom when its enemies emerge from the murk? Though some predators attack unexpectedly, preying on a single oblivious target, other times sea creatures are aware of imminent danger and perform sneaky survival strategies. Swarming in massive schools, some fish are able to swerve chaotically together in the water, distracting a hunter's gaze from a single target. The predator will almost always leave with a meal, but each individual fish has a higher chance of swimming free. Others hide and disguise themselves to throw the threat off their tail, but one step out of line and the predator has won.

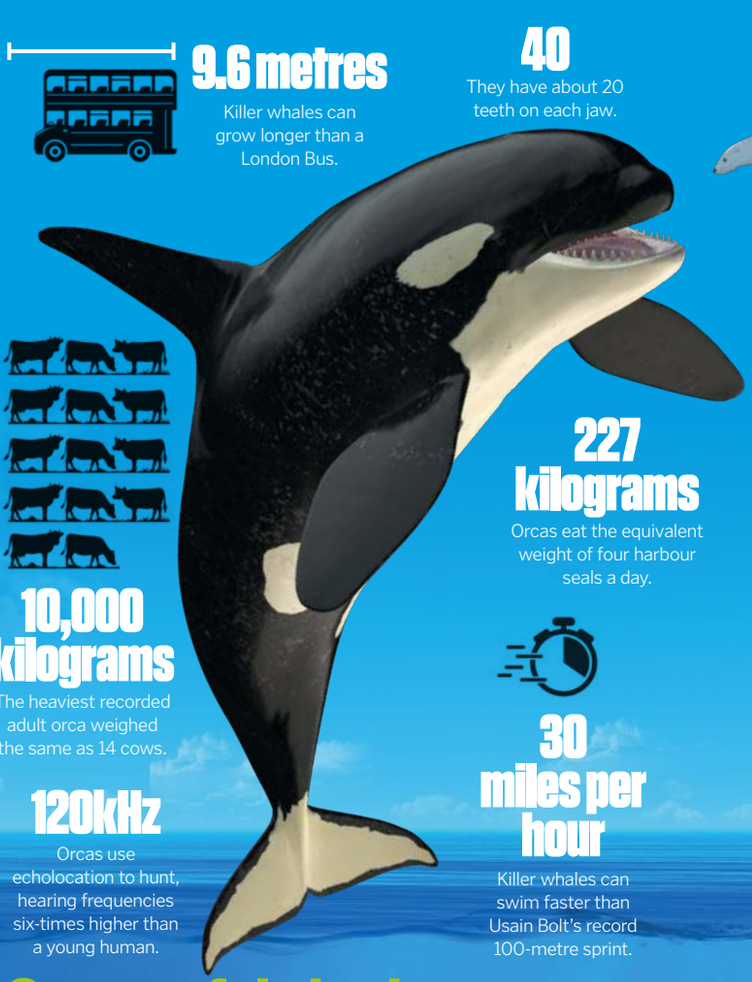
Most marine life lives in the upper half of the sea, with hunting options becoming sparse in the deepest zones. Where food is more challenging to find, hunters have evolved to execute hunts more masterfully, with songs and light displays. The ocean is proof that even the most beautiful creatures can be the deadliest monsters.

TOP OF THE FOOD CHAIN

Killer whales vs great whites

How do two of the largest ocean predators compare?

Orcas and great white sharks sit at the top of the food chain. These rulers of the sea eat with ease, but with contrasting hunting techniques and individual strengths, how would the two fare against each other? These apex predators have enough on the menu, but if it came to a battle to the death, evidence shows an orca might just take the win. In the past, examination of great white carcasses found in the water or washed ashore have shown some to have a missing liver, with wounds that correlated to an orca's bite.



9.6 metres
Killer whales can grow longer than a London Bus.

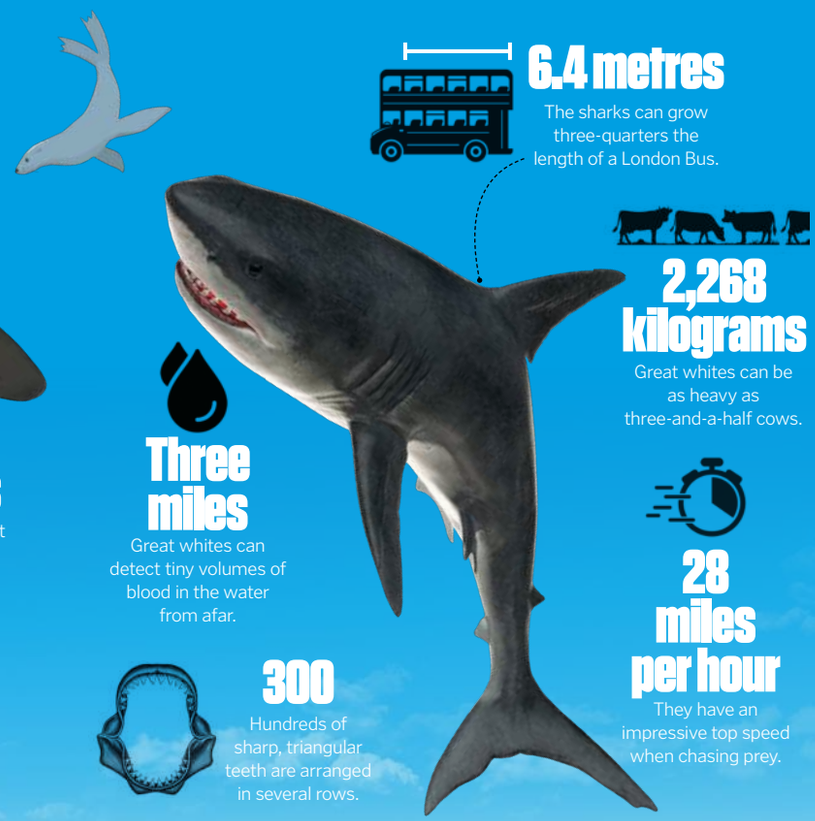
40
They have about 20 teeth on each jaw.

10,000 kilograms
The heaviest recorded adult orca weighed the same as 14 cows.

120kHz
Orcas use echolocation to hunt, hearing frequencies six-times higher than a young human.

227 kilograms
Orcas eat the equivalent weight of four harbour seals a day.

30 miles per hour
Killer whales can swim faster than Usain Bolt's record 100-metre sprint.



6.4 metres
The sharks can grow three-quarters the length of a London Bus.

2,268 kilograms
Great whites can be as heavy as three-and-a-half cows.

Three miles
Great whites can detect tiny volumes of blood in the water from afar.

300
Hundreds of sharp, triangular teeth are arranged in several rows.

28 miles per hour
They have an impressive top speed when chasing prey.

Three metres
Great whites can jump high out of the water when chasing seals.

9,900 kilograms
Each year these sharks eat over four times their own body weight in food.

Successful sharks

© Getty

Bull shark

Max size: 3.5 metres
Speed: 11 miles per hour
Main prey: Bony fish and small sharks

Using the bump-and-bite technique, a bull shark will headbutt and snap at its victim until it is unable to move.

© Getty

Oceanic whitetip

Max size: Four metres
Speed: Six miles per hour
Main prey: Bony fish and squids

Being relatively slow sharks, oceanic whitetips will swim near the top of the water, spying on potential prey below.

© Getty

Shortfin mako

Max size: 3.8 metres
Speed: 35 miles per hour
Main prey: Squid and bony fish

The fastest shark will usually swim at high speeds in a figure of eight before it hurtles towards its prey with its mouth open.

© Getty

Tiger shark

Max size: 7.6 metres
Speed: 20 miles per hour
Main prey: Fish, stingrays, seals and squid

Eating almost anything they can hunt, they repeatedly climb and dive as they swim, searching a wider area.

VICIOUS VENOM

Toxic attackers

How these aquatic assassins catch dinner

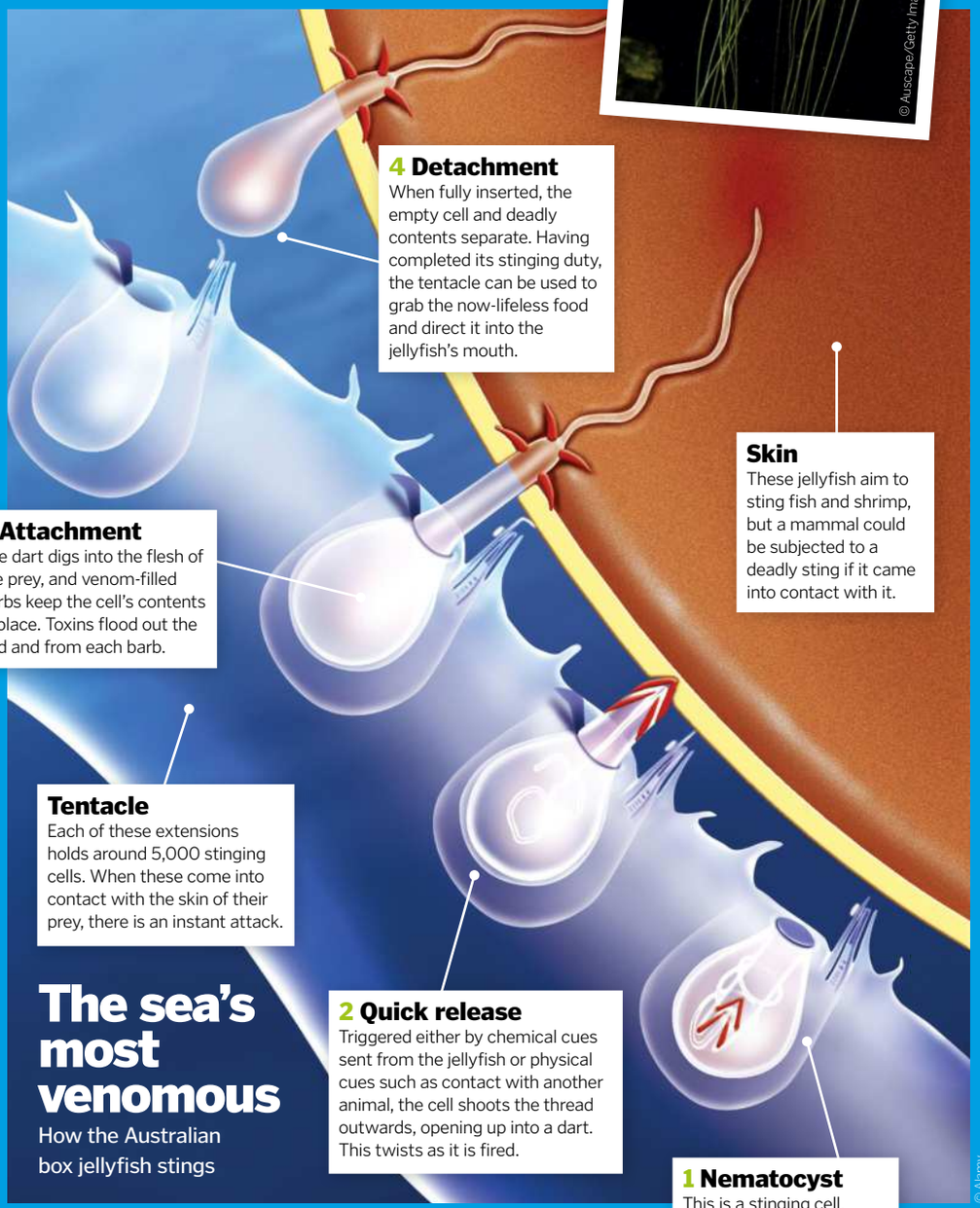
From snakes and stonefish to octopuses and sea slugs, many hunters of the sea use venom to immobilise or kill their prey. A hunting octopus, for example, can either release venom into the surrounding water, or create a wound with its mouth to direct the poison straight into their victim's body.

Of all the toxic creatures in the ocean, the most venomous have no sharp tools. They drift brainless and transparent through the water and can look deceivingly unthreatening, like the Australian box jellyfish. Below their cubic bodies, three-metre-long tentacles dance in the water. It is these lacy extensions that need to be avoided by animals who wish to stay alive. The jellyfish needs to kill with venom before eating its victim, otherwise its soft body risks being torn apart by the desperate animal. One thing which makes this species more dangerous than other jellyfish is their ability to swim rather than float with the tide. This means they are more difficult to avoid, especially as they have clusters of eyes to observe their surroundings with.

"Of all the toxic creatures, the most venomous have no sharp tools"

© Auscape/Getty Images

Australian box jellyfish are found in the warmer waters surrounding Australia



4 Detachment
When fully inserted, the empty cell and deadly contents separate. Having completed its stinging duty, the tentacle can be used to grab the now-lifeless food and direct it into the jellyfish's mouth.

Skin
These jellyfish aim to sting fish and shrimp, but a mammal could be subjected to a deadly sting if it came into contact with it.

3 Attachment
The dart digs into the flesh of the prey, and venom-filled barbs keep the cell's contents in place. Toxins flood out the end and from each barb.

Tentacle
Each of these extensions holds around 5,000 stinging cells. When these come into contact with the skin of their prey, there is an instant attack.

2 Quick release
Triggered either by chemical cues sent from the jellyfish or physical cues such as contact with another animal, the cell shoots the thread outwards, opening up into a dart. This twists as it is fired.

1 Nematocyst
This is a stinging cell, designed to paralyse prey. Coiled inside this spherical capsule is a barbed thread which injects venom.

© Alamy

The sea's most venomous

How the Australian box jellyfish stings

Australia's aggressive 'salties'

Saltwater crocodiles lurk along the coastline of Australia and are the largest of all crocodiles and alligators on the planet. But it isn't purely their size that makes them such ferocious predators. Their snapping set of sharp teeth and frequent displays of aggression put any animal in danger when approaching their territory. This includes humans.

Saltwater crocodiles are difficult to see, as they hide just beneath the water's surface. They can burst from their resting place to tear apart sea creatures as high up in the food chain as sharks. They also snack on birds resting or flying near the surface, and they can pounce on land dwellers with their fast-moving legs, charging out of the water at speeds of over 26 miles per hour. From top to bottom these armoured beasts are equipped for a fight, and can often be seen using their tails as a thrashing weapon.

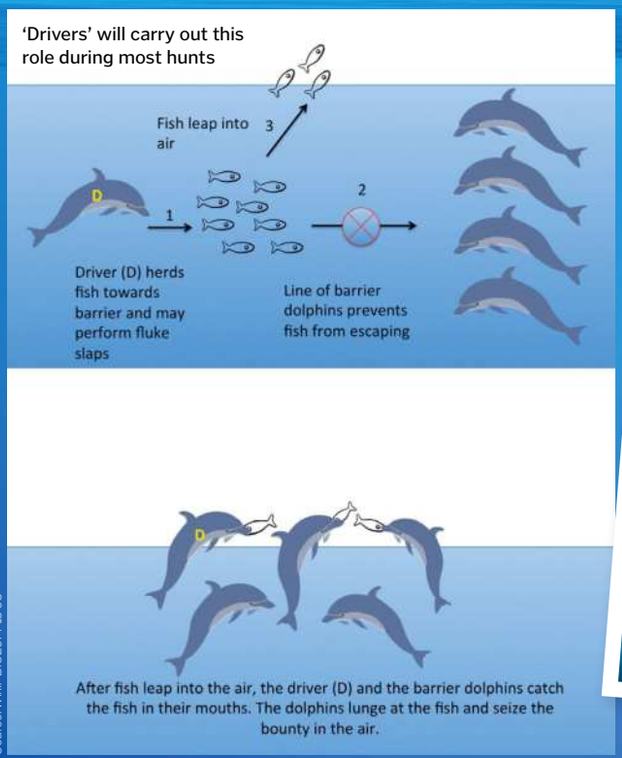
Saltwater crocodiles' teeth can be up to 13 centimetres long

© Getty Images/ Bernard Radvaner

TACTICAL TEAMWORK

How animals hunt in teams

Greater numbers doesn't always mean greater reward, as some marine species work best alone in sneaking up unseen. However, others use larger numbers to surround and control their prey. Bottlenose dolphins, for example, have allocated roles. Groups have been seen sticking to the same jobs each time food is required, with all their cooperative hunting involving 'drivers', which shepherd schools of fish into a suitable area, and 'barriers', which block the fish and steer them to the surface. Other groups have more complex strategies, requiring more jobs.



Source: Wiki/BIO267F1303

"Others use larger numbers to surround and control their prey"

Barracuda trap smaller fish by circling around them in groups

Interspecies attack

A group of the same species teaming up on their prey is a common occurrence in the wild ocean, but in some rare cases, two individuals from different species can attack their prey together. This plays on the different strengths of the animals to make their hunting game much more efficient.

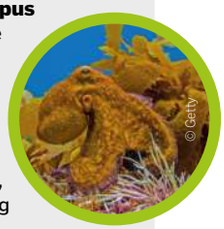
The first observed example of this is the relationship held between the moray eel and the grouper fish. To begin, communication needs to take place between them. Initiating the hunting, a grouper will swim over to an eel, shaking its head and wiggling its fins. The moray eel knows that this is a friendly invitation for a hunt, and the eel may decide to follow the fish.

Smaller reef fish will usually hide from groupers by swimming within the corals, and will avoid eels by darting out into the open water. By working together, the grouper can direct prey into the coral for the eel, while the eel can do the opposite, providing food for the grouper. This method is around five-times more effective for both the animals than hunting alone, and because they swallow the fish whole, there is no fighting over scraps.

The grouper (left) and moray eel (right) seem unlikely hunting partners

5 FACTS ABOUT UNIQUE TECHNIQUES

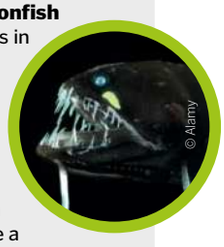
1 SHOCKING Electric ray
With tactics to defend themselves and to catch their prey, these rays have electric muscle cells that can deliver 400 rapid electric shocks in a row, each containing 45 volts.



2 TRICKING Octopus
Blending into the background, prey swim right up to them. They have even been known to tap prey on the back with a tentacle, sending them darting straight into their open mouths.

3 SHOOTING Archer fish
Residing in estuaries, these small fish don't appear too threatening, but they target unsuspecting prey outside the water. Making a barrel with the tongue, they close their gills and shoot water at branches above the surface, aiming for beetles and other insects to knock down and eat.

4 PUNCHING Mantis shrimp
Using their advanced eyesight, seeing more colours than any other species, they pinpoint a target. Then they punch with hammer claws, 50-times faster than humans can blink. This heats the surrounding water to the temperature of the Sun's surface for a moment.

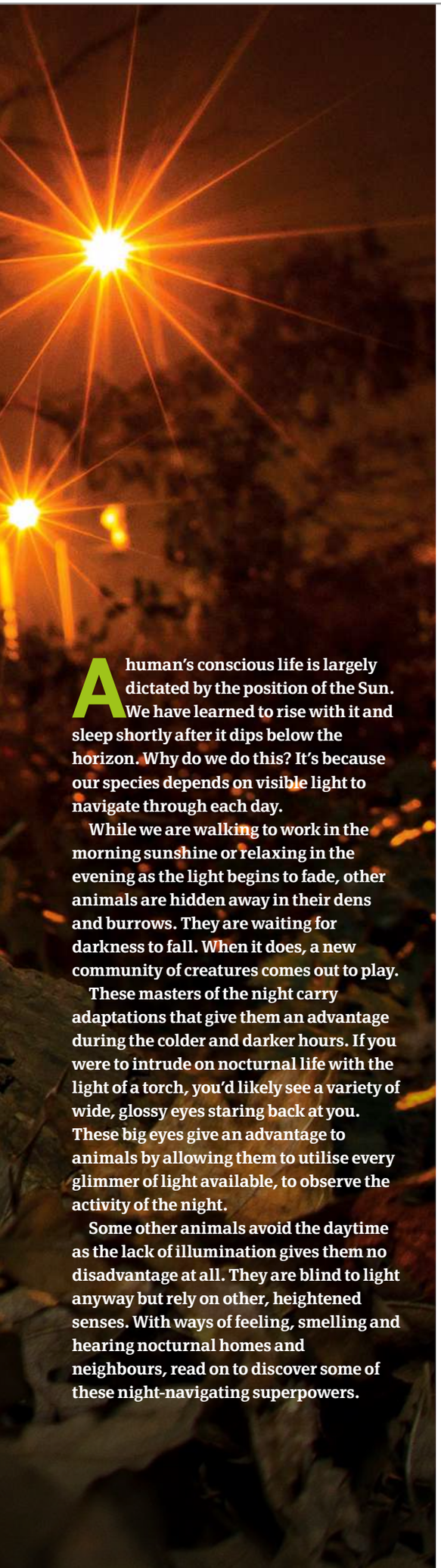


5 GLOWING Scaleless dragonfish
This fanged fish lurks in the depths of the ocean, occasionally lighting up with bioluminescent cells that span the length of its body. Attracting other fish with its display, once a meal gets a bit too close, its long teeth bite down.

How animals see in the DARK

Under the limited light of the Moon, discover the creatures that thrive in the night

Words by **Ailsa Harvey**



Seeing after sunset

© Getty

Human eyes are built for operation in bright daylight and will struggle to see anything on a night lit solely by moonlight. Some of the animals that are active at night require better sight to stay alive, and their eyes have evolved accordingly. In general, the eyes of a nocturnal animal will be proportionally larger than a human's. They work to let more of the limited light in, with widely dilating pupils.

A human's conscious life is largely dictated by the position of the Sun. We have learned to rise with it and sleep shortly after it dips below the horizon. Why do we do this? It's because our species depends on visible light to navigate through each day.

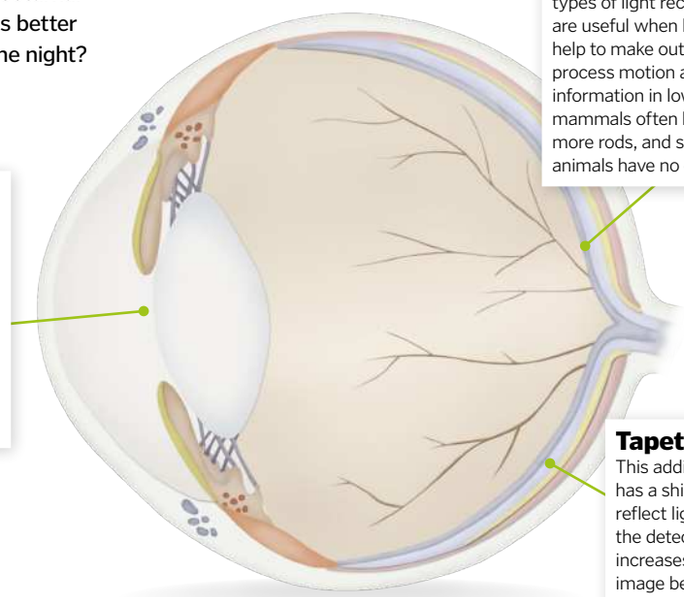
While we are walking to work in the morning sunshine or relaxing in the evening as the light begins to fade, other animals are hidden away in their dens and burrows. They are waiting for darkness to fall. When it does, a new community of creatures comes out to play.

These masters of the night carry adaptations that give them an advantage during the colder and darker hours. If you were to intrude on nocturnal life with the light of a torch, you'd likely see a variety of wide, glossy eyes staring back at you. These big eyes give an advantage to animals by allowing them to utilise every glimmer of light available, to observe the activity of the night.

Some other animals avoid the daytime as the lack of illumination gives them no disadvantage at all. They are blind to light anyway but rely on other, heightened senses. With ways of feeling, smelling and hearing nocturnal homes and neighbours, read on to discover some of these night-navigating superpowers.

Mammal eyes

What makes nocturnal mammals' eyes better equipped for the night?



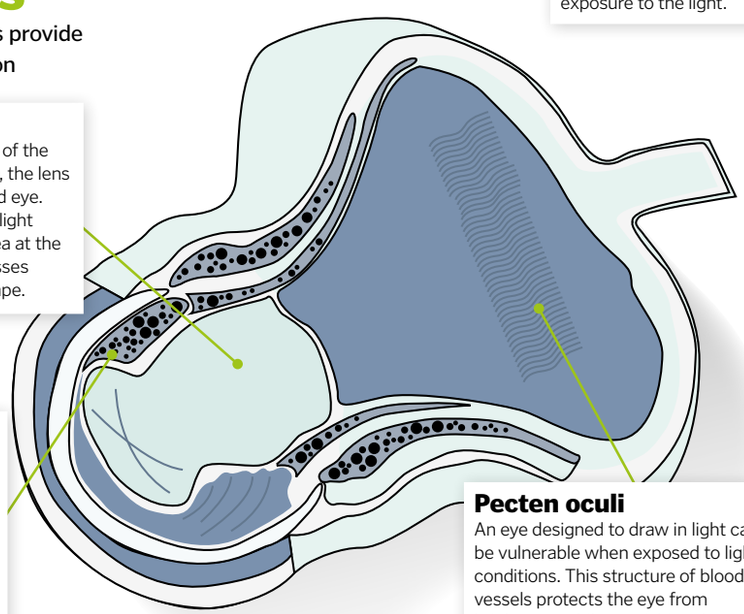
Refined retina
The retina at the back of the eye contains cones and rods, different types of light receptor cells. Cones are useful when light is bright and help to make out details, while rods process motion and other visual information in low light. Nocturnal mammals often have proportionally more rods, and some nocturnal animals have no cones at all.

Wide-eyed
The eye is usually large to provide more room for the pupil to expand. This wideness increases the brightness of the image on the retina.

Tapetum lucidum
This additional layer of cells has a shiny surface and can reflect light back through the detector cells. This increases the chance of an image being detected, providing more than one exposure to the light.

Bird eyes

Tubular-shaped eyes provide owls with night vision



Tubular focus
While the outer surface of the eye covers a larger area, the lens sits inside this elongated eye. This enables it to focus light onto a concentrated area at the back of the eye as it passes through the thinned shape.

Sclerotic ring
These rings of bone help to support the eyes' shape. Holding them firmly in place, the eyes don't move in the socket. Instead the owl rotates its whole head 270 degrees.

Pecten oculi
An eye designed to draw in light can be vulnerable when exposed to lighter conditions. This structure of blood vessels protects the eye from brightness while nourishing the retina.

Thermal vision

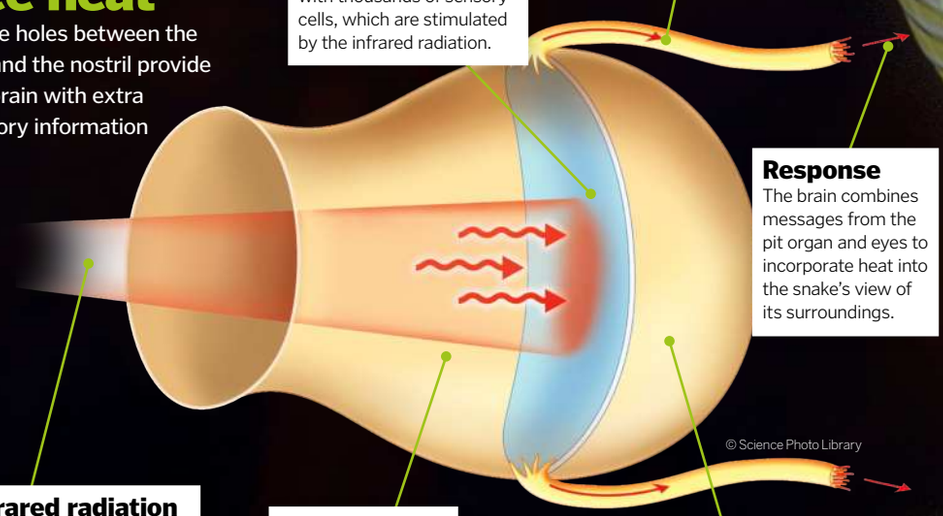
Using infrared alone, snakes have been able to successfully pounce on prey while their eyes are covered

For snakes that hunt during the darkest hours of the night, spotting a tiny, scurrying mouse in the pitch black might sound like an impossible task. In reality, some snakes have an incredibly advantageous signalling system in their heads: they are able to see heat.

Warm-blooded rodents are a large portion of a snake's diet, and with mice only giving off a small amount of body heat, this navigational skill is efficient and quick enough to allow precise and successful hunting at night. By the time the snake pounces, the mouse has minimal chance of spotting their impending death in the dim conditions.

How snakes see heat

These holes between the eye and the nostril provide the brain with extra sensory information



Messengers
Heat detection information is fired to the brain through the nervous system. The specific part of the brain is the optic tectum.

Sensory membrane
This membrane is packed with thousands of sensory cells, which are stimulated by the infrared radiation.

Response
The brain combines messages from the pit organ and eyes to incorporate heat into the snake's view of its surroundings.

Infrared radiation
The heat detected from the prey enters the pit organ through holes in the snake's face. It then reaches the exposed membrane.

Inner cavity
This cavity insulates the sensitive membrane from the back wall of the pit.

Outer cavity
Because this area is about as wide as it is deep, the images from the membrane can be blurry.

5 FACTS ABOUT NIGHT-VISION ANIMALS

1 Owl
At the back of their eyes, these birds have almost a million rods per square millimetre. In comparison, humans have just 200,000 of these photoreceptors in total.

2 Fruit bat
Said to have the best vision of all flying mammals, fruit bats combine enhanced night vision with their keen sense of smell while hunting for food.

3 Elephant hawk-moth
These moths not only have eyes that can see shapes well at night, but also colour, being able to distinguish between colours in low light.

4 Tarsier
This small primate has adorably large eyes, roughly the same size as its brain. Though they can't see colour too well, their massive eyes mean they can see in extremely dim light.

5 Colossal squid
At 27 centimetres in diameter, these beasts' eyes are the size of footballs, and are the largest on Earth. At the dark depths of over 2,000 metres underwater, they need their expert night vision.

Stargazers

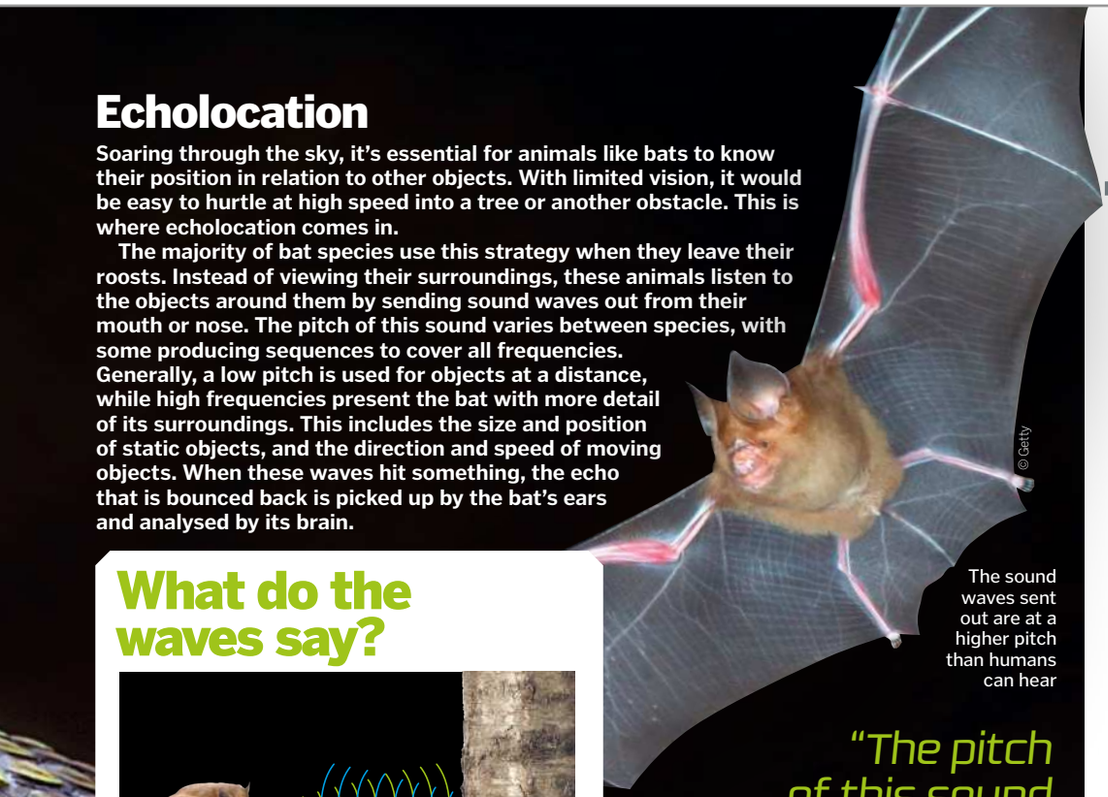
The night sky presents patterns and points of light in the form of stars. In beautiful contrast to the black backdrop, it is no wonder that some species are drawn to their glow. Stars can help to guide animals in different ways: seals can recognise the unique patterns, some birds use a single bright star to find their way and dung beetles follow the path of the Milky Way's spiral arm. Unlike seals, insects are too small to be able to notice each individual star, but the luminous band created by our galaxy's arm is clear enough to provide direction and keep them moving in a straight line.

There are an estimated 100 to 400 billion stars in the Milky Way, each lighting insects' paths

Echolocation

Soaring through the sky, it's essential for animals like bats to know their position in relation to other objects. With limited vision, it would be easy to hurtle at high speed into a tree or another obstacle. This is where echolocation comes in.

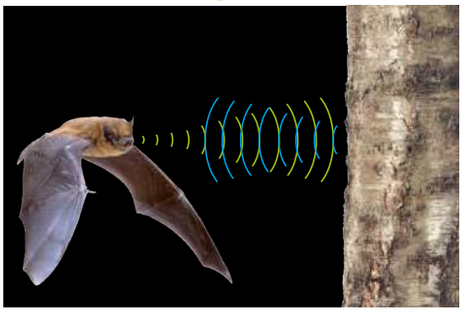
The majority of bat species use this strategy when they leave their roosts. Instead of viewing their surroundings, these animals listen to the objects around them by sending sound waves out from their mouth or nose. The pitch of this sound varies between species, with some producing sequences to cover all frequencies. Generally, a low pitch is used for objects at a distance, while high frequencies present the bat with more detail of its surroundings. This includes the size and position of static objects, and the direction and speed of moving objects. When these waves hit something, the echo that is bounced back is picked up by the bat's ears and analysed by its brain.



© Getty

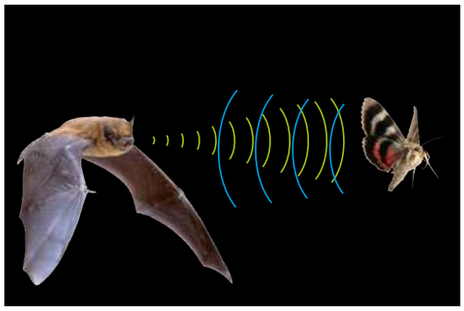
The sound waves sent out are at a higher pitch than humans can hear

What do the waves say?



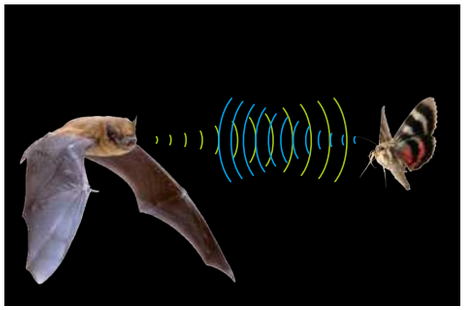
Still object

When sound reaches an object, it's deflected in the opposite direction. The time between sending and receiving the sound tells the bat how close something is.



Moving away

When the object detected is moving away from the bat, the returning waves will produce a lower pitch than that sent out.



Moving closer

Objects approaching the bat will return each sound wave closer together, producing a higher pitch than that originally produced.

© Getty

"The pitch of this sound varies between species"

Bogong moths look for visual landmarks, as well as analysing the planet's magnetic field

© Alamy

Hair tactility

If you were stuck in a completely dark room, how would you walk to the door? Chances are you would put your hands out in front of you, feeling out your way to safety. Animals use the same method, but with a more technical and efficient system.

Sensitive whiskers on the snouts of animals such as lemurs, badgers and dormice can aid foraging in the most complex habitats. Spending most nights in the dangerous heights of the trees, hazel dormice need these feelers so that they know where gaps lie between branches. They move their whiskers in a movement called 'whisking'. Brushing backwards and forwards in a cyclic motion, this is one of the fastest movements made by mammals. Special facial muscles found in whiskered animals allow these speedy movements so that the whiskers can constantly brush against surfaces as the animals travel. The uneven surfaces surrounding them are detected by hundreds of motion sensors in these modified hairs.

The largest dormice can jump three metres

© Getty

Magnetic mapping

If you've ever opened your window at night to see a moth mindlessly following the light into your room, you may be fooled into thinking that these insects have developed rather limited navigational skills. The truth is that moths are extremely well-evolved to fly at night, using a sense called magnetoreception.

Australia's bogong moths were the first insects discovered to have a built-in compass, allowing them to follow the Earth's magnetic field for migration. Along with nocturnally migrating birds, these creatures are able to find specific locations in the country.

It is believed that these insects have small magnetite crystals within their nervous system which are extremely sensitive to Earth's magnetic field. This signal changes with the moth's direction of flight, allowing them to check their position with Earth's and keep them heading on the right flight path.

RISE OF THE MARSUPIALS

Why are Australia's indigenous mammals so different to animals in other continents?

Words by **Scott Dutfield**

Australia is no stranger to the weirder side of evolution, with the likes of patchwork platypuses and egg-laying, hedgehog-like echidnas roaming the land. However, it has also become the home of one particular group of mammals: marsupials.

Found hidden beneath the ground, hopping through grasslands or hanging among treetops, Australia hosts a majority of Earth's marsupials. Around 250 species of these pouch-bearing parents live throughout the southern continent – that's more than anywhere else in the world. There are 120 species in South America and only one species, the Virginia opossum, is found in North America. This abundance has led some to believe that marsupials first evolved in Australia. However, that is not the case. It took millions upon millions of years for marsupials to make their way over to what would become the world's smallest continent.

> "This created an opportunity for early marsupials to use land bridges between what later became separate continents"

What does it mean to be a marsupial? How have the different species adapted as parents and what was their evolutionary journey across half the world to build the current kingdom of the marsupials like? Home to the springing kangaroo, tree-clinging koala and burrowing wombat, Australia is well known for the diversity in its species and for being home to mammals that are rarely found around the rest of the world. The kangaroo, koala and wombat are native Australian species – and are all marsupials, of course. This means that the way they give birth and support their young is different from other placental mammals such as humans, elephants and bears.

Inside a koala's pouch

Discover how these tree-hugging mammals grow

Gestation
After conception the developing embryo will gestate for 35 days, growing into a pink baby, called a joey, around two centimetres long.

Birth
Blind and yet to develop ears, the joey will emerge from the birth canal and climb into the pouch.

The climb
Driven only by a sense of smell, the joey climbs to its mother's nipple, where it attaches. It drinks only milk for six to seven months.

Many marsupial babies are born without the ability to see or hear

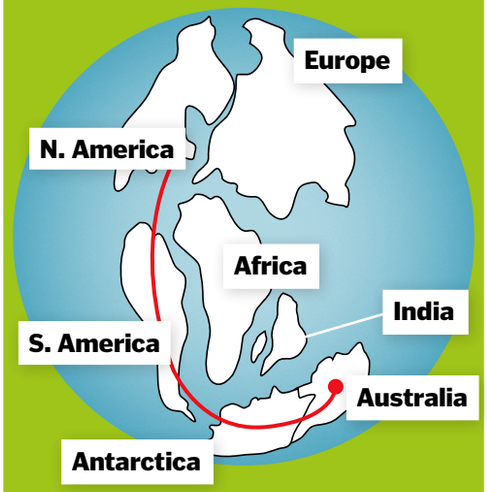
Motherhood
Over their 12-year life span, female koalas will only have five or six offspring.

Independence
After a year the fully developed juvenile koala will stop drinking milk and forage for itself.

New food
Before the young koala is ready to leave the pouch it leans out to feed on a type of faeces produced by the mother called pap before delving into a diet of eucalyptus leaves.

Travelling to Australia

How marsupials migrated to the other side of the world



The journey begins

Around 66 million years ago marsupials made their way down from North America to South America. Although at the time the two land masses were not connected, it's thought land bridges or islands may have allowed them to migrate.

Heading south

Once in South America the number of different marsupial species increased, and although today most of those species are extinct, South America still has the second-highest diversity of marsupials.

Crossing Antarctica

While South America was still attached to Antarctica and Australia – before splitting 40 to 35 million years ago – some marsupial species hot-footed across the land masses to populate Australia. During the time of their evolutionary migration, Antarctica, like many other parts of the world, would have been filled with tropical rainforests.

New home

The first fossil evidence of marsupials in Australia dates back 55 million years. Since the continents broke apart Australia could not be reached by the placental mammals dominating the rest of the world, leaving marsupials to thrive.

Placental mammals carry their offspring internally, where they are nourished by a specialised organ called the placenta until the developing fetus is fully grown and ready to be born. Marsupial babies, however, are born at a stage when they are still developing.

Rather than facing the outside world immediately as human babies do, a marsupial joey will climb its way into a protective pouch on the mother where it will continue to develop until it's fully formed. This also means gestation time can be surprisingly shorter in some species compared to their placental cousins. For example, the mouse-like stripe-faced dunnart has a gestation period of only 11 days before the fetus is birthed into its parent's poach.

But why is Australia inhabited by so many of these marsupial mammals compared to the rest of the world? It's easy to assume that marsupials must have evolved on the Australian continent because it's an island without a geographical bridge over which they could venture outside its borders and form new populations. But that's not strictly true. The first marsupials appeared in what is now North America 160 million years ago, when Earth's supercontinent Pangea connected the world's land masses as one. This created an opportunity for early marsupials to use land bridges between what later became separate continents, allowing them to move around to form new populations. Over millions of years the ancestors of modern-day marsupials found themselves on the Australian continent without strong competition from the placental mammals evolving elsewhere around the world.

Modern-day marsupials

Meet just a handful of the 250 marsupial species alive in Australia today

Wombat

Weighing up to 36 kilograms, these robust mammals begin life gestating for 21 to 30 days before they climb into their mother's pouch for another five months. Finally they emerge, frequently revisiting the pouch for another two months whenever they feel threatened. Dwelling in forests and grasslands, these vegetarians dig deep burrows, forming complex tunnels and chambers.

Honey possum

These marsupials are some of the smallest of the bunch, weighing up to just ten grams and fitting easily in the palm of your hand. As extremely small adults, their young only weigh 0.005 grams, the smallest of any mammal born in the world. Honey possums spend their lives predominantly feasting on the nectar of plants, consuming around 1.5 teaspoons of nectar per day.

Quokka

Often seen with what appears to be a smile on their faces, Quokkas are one of Australia's eternally pregnant marsupials. With the ability to give birth to a fetus after 27 days, while the new offspring is suckling in the mother's pouch, another fetus can begin to grow internally. This baby conveyor belt is believed to be a good defence mechanism for the Quokka. When threatened it can evict the suckling young as a distraction to escape, reassured that another baby is growing inside.

Numbat
Around 50 centimetres in length including their bushy tails, these small marsupials gestate for 14 days then carry their pouch-bound fetus for nine months before it is able to forage for insects itself. Numbats have a long, slender tongue that scoops up termites from leaf litter and deadwood – up to 20,000 of them a day! There's enough water in these termites that numbats don't have to drink any.

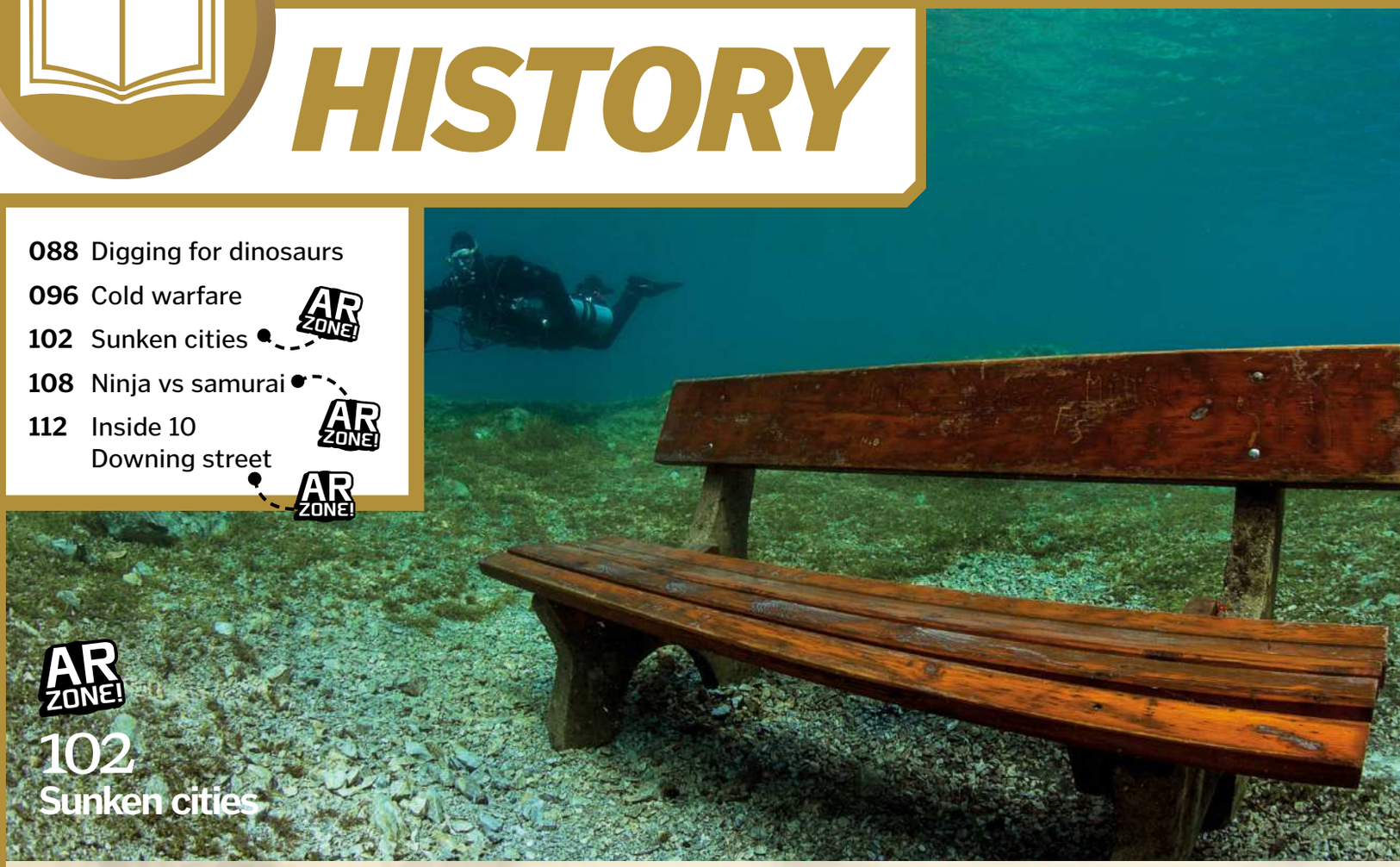
Greater bilby
They might look like rabbits, but they are far from it. This endangered marsupial lives in semi-arid shrubland and has large ears to compensate for its poor eyesight. The greater bilby is capable of giving birth up to four times a year, producing eight offspring at a time. By only five months old, these marsupials are fully grown and ready to reproduce.

"Often seen with what appears to be a smile on their faces, Quokkas are one of Australia's eternally pregnant marsupials"

Eastern quoll
The size of a small domesticated cat, the eastern quoll can be found in southeastern areas of Australia in dry grassland feasting on insects and small mammals. These marsupial mothers can grow 30 fetuses at a time. However, they are only able to feed between six and eight babies in their pouches, leading to many fatalities. After only ten weeks in the pouch the babies are placed in grass-lined dens, allowing the mother to hunt and retrieve food.

Source: Wiki / PD / CC / Reto Stöckl / NASA Goddard Space Flight Center

HISTORY



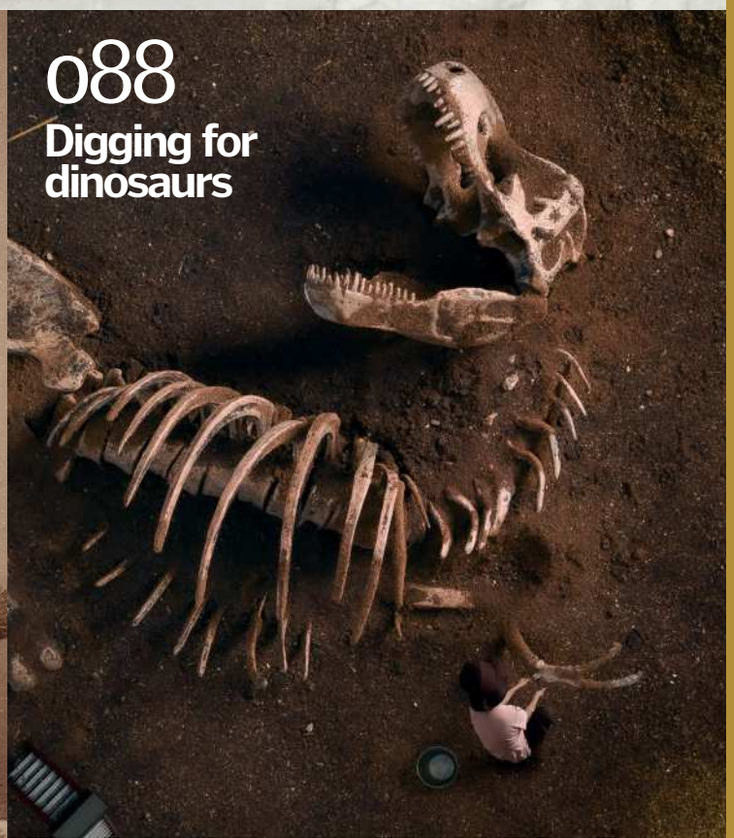
AR ZONE!

102
Sunken cities

AR ZONE!

112
Inside 10 Downing street

AR ZONE!



Though rarer, entire skeletons have been found perfectly preserved

Excavating is a slow process to avoid damaging the find

DIGGING FOR DINOSAURS

Discover how a fossil hunter recently discovered a new ancient species. Could you make the next big find?

Words by **Ailsa Harvey**

How do you look for something that you aren't yet aware existed, from a world you can only try to imagine? It might seem impossible for us to study a species that we have never coexisted with, but this is something palaeontologists and fossil hunters do every day.

When humans first encountered dinosaurs, they had been extinct for over 65 million years. Everything we have come to know about dinosaurs today has been learned through our understanding of the planet's geology and analysing the ancient remains of these creatures. For this to happen, dinosaurs needed to have a lasting impact on the world, enduring tens of millions of years held inside solid rock. Luckily the remains of many types of dinosaur were preserved in the ground until humans could uncover them – and their secrets.

Fossils are impressions of ancient life, contained in the Earth's crust as a memento of life before the present. To palaeontologists they are hidden treasures, each with valuable information to share about a past geological and environmental age. The secret to their lasting form comes from the way they died. To become a fossil a dinosaur needed to take its last breath near water, or to have been buried alive.

Most dinosaurs wouldn't have died this way, so their remains would have deteriorated and can never be discovered. However, even for those that perished in one of these two ways, their bodies had to be surrounded by certain essential minerals to convert them into rock. Fossils are formed deep underground, where oxygen levels are so scarce that no bacteria can survive there. This means the body is unable to decay and lose its shape.

It's odd to think that these bones could be frozen in time only to be neatly retrieved from the ground as an almost-undisturbed stone skeleton. In some cases, not only are scientists presented with a perfect anatomical specimen to study, but they get an insight into a day in the life of a dinosaur – albeit their last day. Those that were suddenly buried alive can be retrieved in the exact position they died in. These are extremely rare fossils, but can provide information about the way a species lived.

Around the world, new dinosaur species are constantly emerging from rock faces, sandy dunes and clay-rich soils. But why are they being found now? To retrieve a fossil from sediment, the dinosaur first needs to be within reach. Sometimes it simply means being in the right place at the right time. You need to be near the land where the fossil has been held for millions of years just after the forces of nature have removed its rocky casing. The fossil then needs

5 FOSSIL TYPES

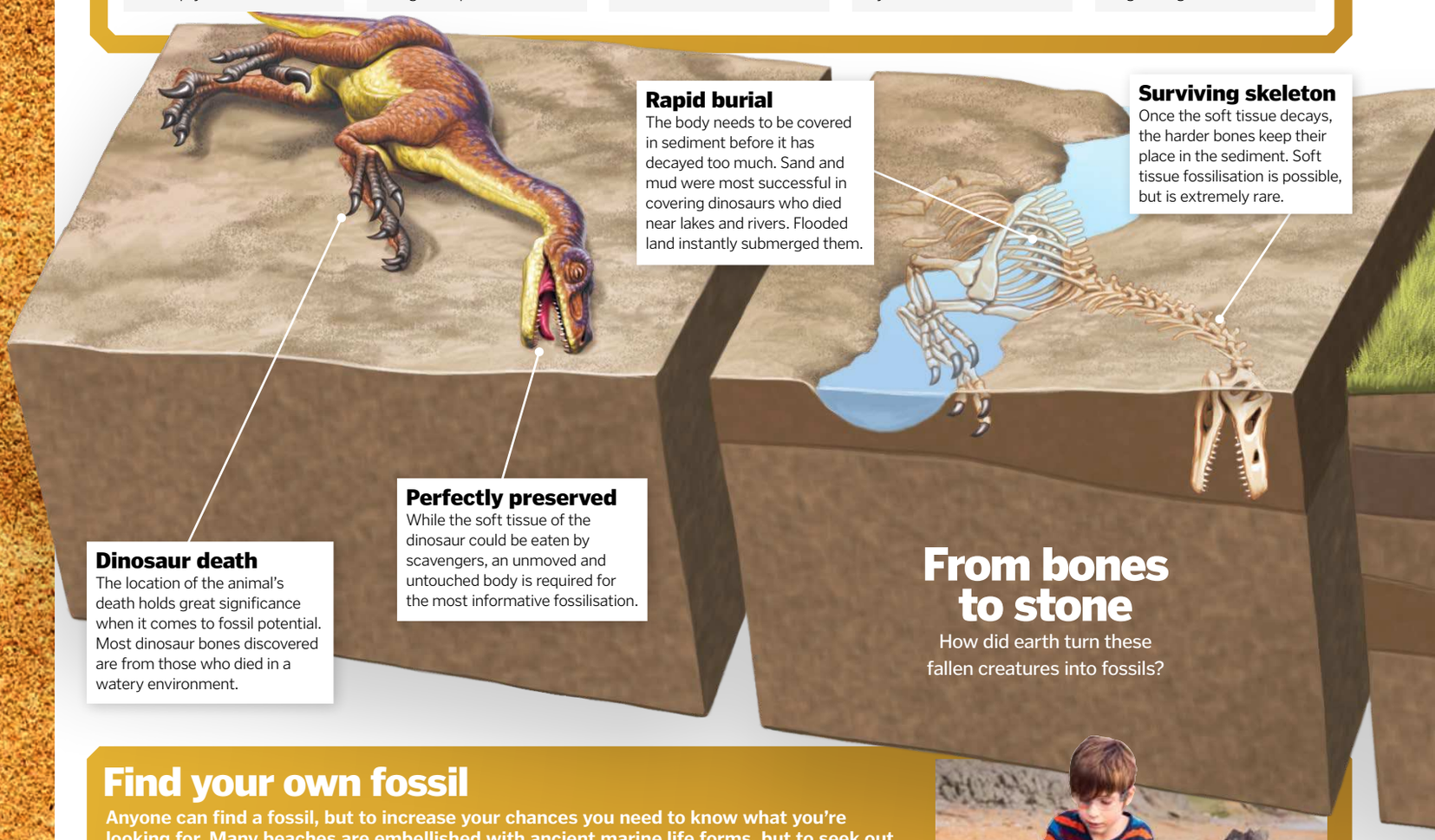
Mold
The rock of a mold fossil details the outside of the organism. After the sediment around it hardens, the buried plant or animal is dissolved by water, leaving an empty mold for a fossil.

True form
These fossils are created when the body of an organism is replaced with rock. It displays the organism's true form in great detail, rather than just being an impression.

Trace
Trace fossils aren't necessarily physical remains of an organism, but their formation displays traces of their existence. Examples include footprints, tooth marks and nests.

Carbonised
Created when a dead organism is buried on flat rock. Over time a thin carbon film is deposited onto the rock's surface. As the body decays, the carbon layer remains.

Cast
Cast fossils are more advanced mold fossils. Once the mold is created, the hollow area is filled with minerals, which harden to form a rocky version of the original organism.



Dinosaur death
The location of the animal's death holds great significance when it comes to fossil potential. Most dinosaur bones discovered are from those who died in a watery environment.

Perfectly preserved
While the soft tissue of the dinosaur could be eaten by scavengers, an unmoved and untouched body is required for the most informative fossilisation.

Rapid burial
The body needs to be covered in sediment before it has decayed too much. Sand and mud were most successful in covering dinosaurs who died near lakes and rivers. Flooded land instantly submerged them.

Surviving skeleton
Once the soft tissue decays, the harder bones keep their place in the sediment. Soft tissue fossilisation is possible, but is extremely rare.

From bones to stone
How did earth turn these fallen creatures into fossils?

Find your own fossil

Anyone can find a fossil, but to increase your chances you need to know what you're looking for. Many beaches are embellished with ancient marine life forms, but to seek out dinosaur bones you'll need more luck and patience alongside your knowledge.

First, you need to understand the rocks. By finding out how old the rocks are in the area you're searching, you can tune your hunt to the kinds of species you are likely to find. Next, pick your time. You can find fossils all year round, but from November to April is usually best. This is because rough seas and winter winds create movement on the beach, and this time of increased erosion can expose new fossils from the cliffs.

Always ensure you keep safe while searching for fossils. There's no need to climb cliffs, as many can be found loose on the ground. For your first search at least, you should join an expedition organised by experienced fossil hunters. This can provide you with information on what to look for and further useful tips to carry with you on your next hunt.

You can learn how to break rocks without damaging any fossils inside

to be retrieved before the conditions above the ground erode or damage it and render it unrecognisable. The reason that the number of finds has increased in recent years is in large part due to our expanding knowledge of the dinosaurs and the evolving technology that helps us to study them.

More people are out looking for dinosaur fossils today than ever before. We now know where the best places to look are, what kind of shapes the eye should be drawn to and the best times of year to search. Knowing where to look and what to look for has increased the success of beachcombing and geological digs.

> "Sometimes it simply means being in the right place at the right time"

Although learning from previous finds enhances our understanding of what to look for next time, new species are often found in the least expected locations. One of the most recent dinosaur revelations was plucked from a British beach on the Isle of Wight last year, and after thorough research it was revealed to be a new species this summer.

This new species was retrieved from an unusual sediment type where the average fossil collector wouldn't think to search, showing that repeating methods of past finds doesn't always provide new results. This acts as an example that maybe the best way to search for something you don't know exists yet is not to search in conventional places at all. Sometimes the most notable fossils will find you.

The world of the dinosaurs seems so distant, but with every new species found we get closer to it. As our advancing knowledge of the relationship between each species grows, we have learned that dinosaur traits have been carried into the present day – and not just in their fossilised form. Modern birds actually originated in the Mesozoic Era, evolving from the theropod dinosaurs. Members of this group ranged drastically from the immense *Tyrannosaurus rex* to tiny bird-like creatures.

The sheer diversity between dinosaur species that have been discovered so far demonstrates just how much these animals evolved during their time on our planet. With every fossil that palaeontologists research, more pieces are added to the evolutionary story of the dinosaurs.

Perhaps one of the reasons humans have become so infatuated with these beasts that once ruled planet Earth is that we can relate to their domination. As a species that also appears to be thriving in great numbers, humans are discovering through ancient evidence that the forces of nature could overthrow us in an instant, turning us into a fossilised memory on par with the legendary dinosaurs that once roamed the ancient continents.

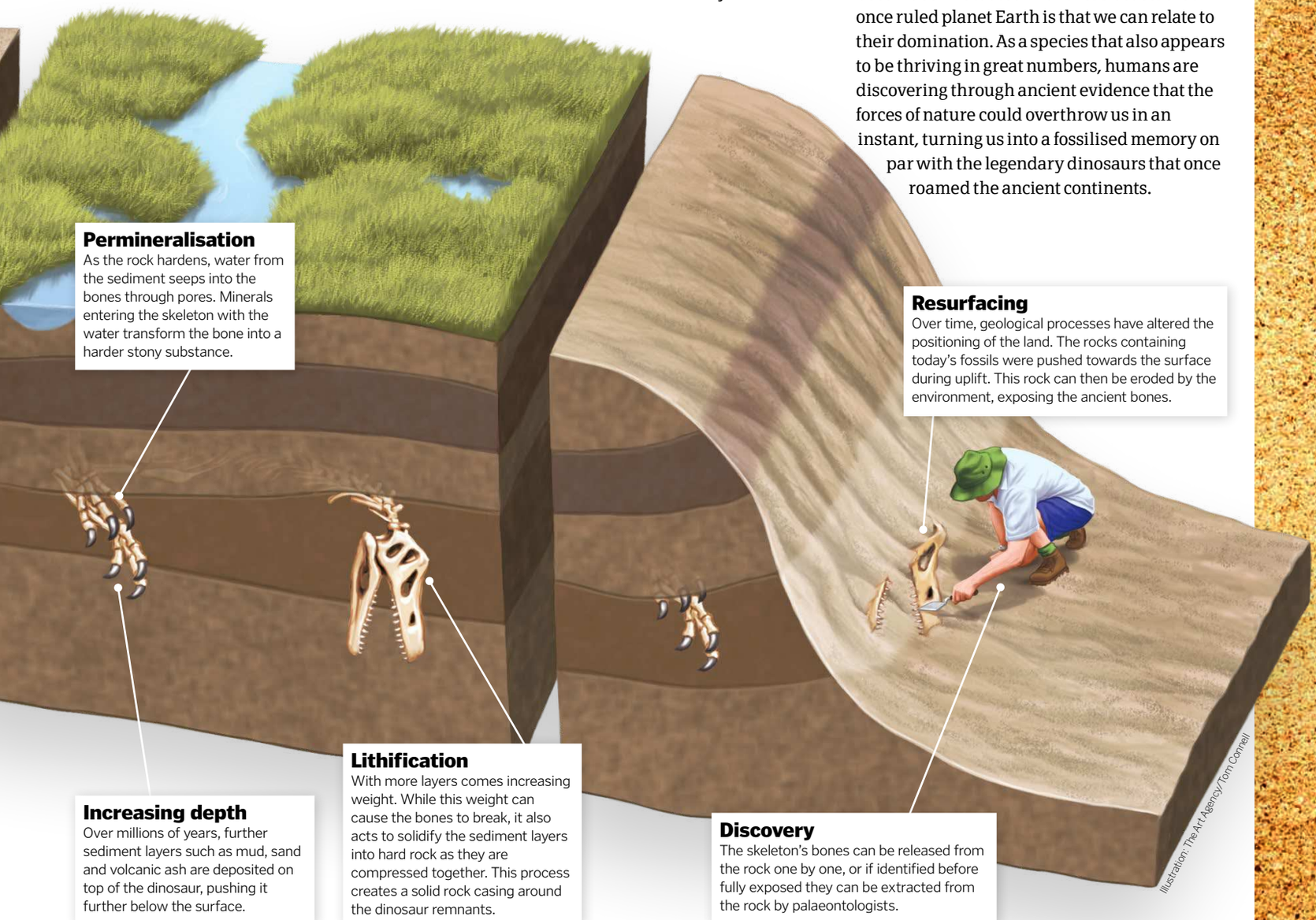
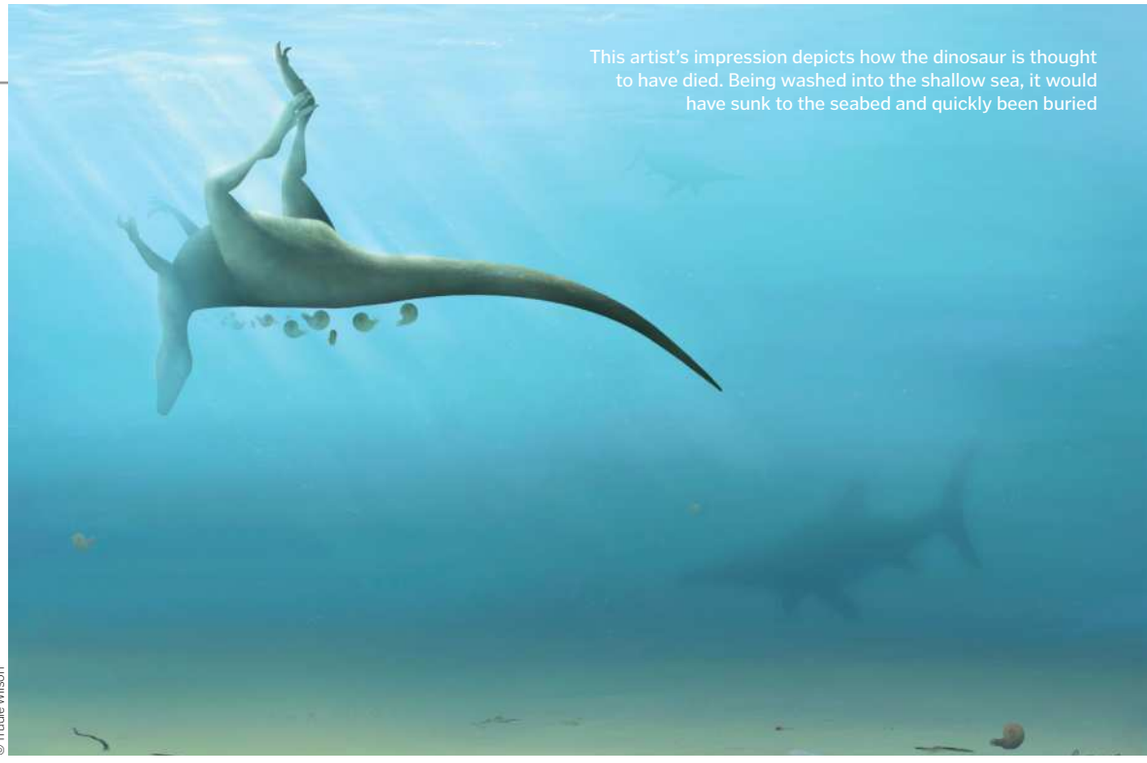


Illustration: The Art Agency/Tom Connell


This artist's impression depicts how the dinosaur is thought to have died. Being washed into the shallow sea, it would have sunk to the seabed and quickly been buried

A new dinosaur

Discover how a new species was uncovered

It was recently revealed that four dinosaur bones, found last year on the Isle of Wight, England, are those of an entirely new dinosaur species. Since October 2019 these bones have been held at the University of Southampton, where palaeontologists have been hard at work trying to discover what animal they belong to. They soon realised, after comparing each minute detail to a computer database, that this species had never been seen before.

Named the *Vectaerovenator inopinatus*, it is a member of the theropod family of dinosaurs, making it a close relative of the *Tyrannosaurus rex*. Its given name sums up many of its discovered qualities.

'Inopinatus' means unexpected. What made these bones particularly interesting to palaeontologists is that they were found in the lower greensand. This is a marine sediment which is a rare location for dinosaur fossils and a likely reason why the species had not been located before.

Neil Gostling, who supervised the study, said: "The Isle of Wight is the best place to find dinosaurs in Europe, but usually these finds are a terrestrial deposit. It is exciting because greensand is 116 million years old, and we have a poor understanding of European dinosaurs in this time period."

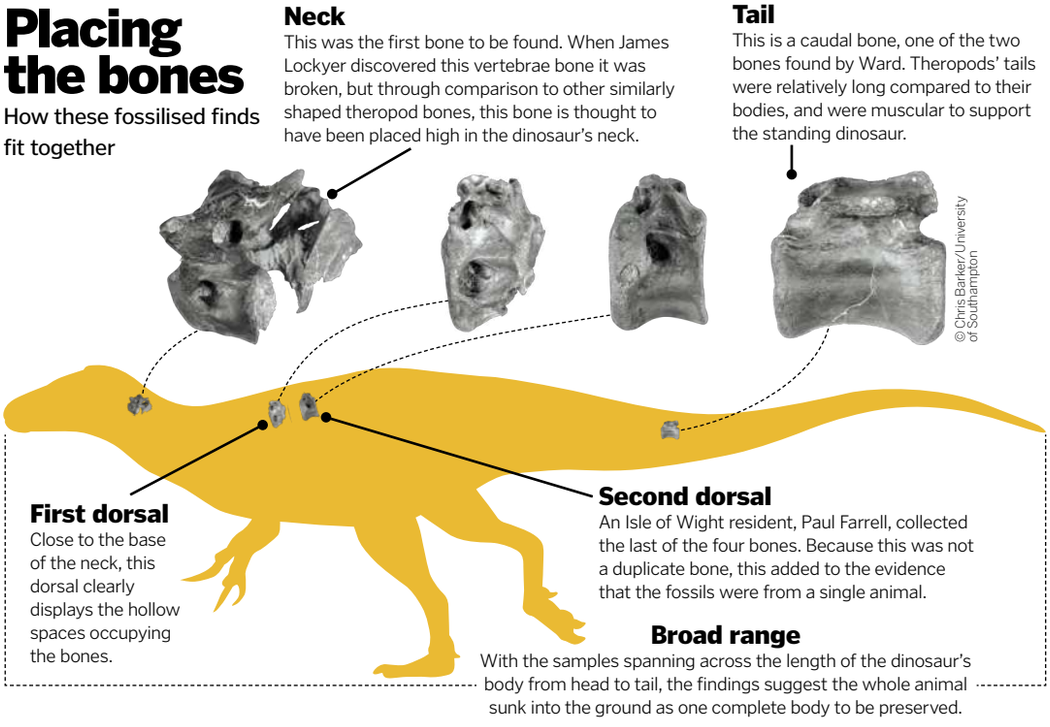
'Aero', which is incorporated into the new species' name, means air in Latin, and refers to the hollow properties of the four bones studied. They have large holes which would have been extensions of lung tissue for gas exchange.

"This is a very efficient way of getting oxygen into the body," Gostling said, "which some other theropods have as well. [The four fossils] don't feel like rock because they're almost hollow."

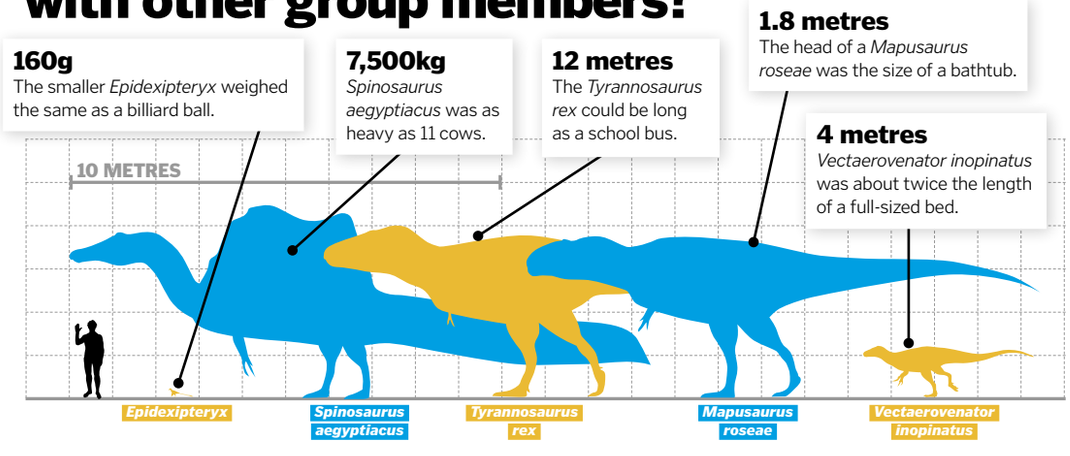
Despite only four bones being studied from this dinosaur, the university has already determined specific details about this ancient creature. Since the release of the findings another two bones from the same species have been handed in, and the researchers hope to soon reveal further information about it.

Placing the bones

How these fossilised finds fit together



How does the new theropod compare with other group members?



Q&A

Fossil hunters who hit the jackpot

Ward discovered two of the dinosaur's bones

Lockyer found a bone from the neck

Robin Ward and James Lockyer weren't expecting to find a new dinosaur species when they visited the Isle of Wight last year. In March 2019 Lockyer discovered one of the dinosaur's bones, and Ward found two more in May. The fourth bone involved in the study of this species was collected by Paul Farrell.

What brought you to the Isle of Wight?

RW: I have been to the Isle of Wight a few times, but it was my daughter who chose to go there this time, as it was her tenth birthday. When we arrived we were too early to check into the hotel, so we decided to go fossil hunting on Shanklin Beach while we waited.

JL: I have been fossil hunting for the last 10 to 15 years and went to the Isle of Wight because it is an area with rapid erosion of the cliffs. Because of that, it's a good place to find fossils.

How did you come across the bones?

RW: As I searched the rocky area, I knew a find was possible because there had just been a high tide, which could uncover fossils from the sand. When I came across the first one on the floor, I videoed myself picking it up and posted it online. I knew it was from a dinosaur. I found the second just five minutes later, about eight feet [2.4 metres] away. I was so chuffed I did a bit of a jig on the beach. It's the find of a lifetime.

JL: I was told I wouldn't find much on Shanklin Beach, but I like to look in areas where others don't. I began searching the foreshore among the rocks and there it was – half a vertebrae – popping out the rocky substrate. I went to wash it in the sea and saw that it had a nice shape to it.

> "I was told I wouldn't find much on Shanklin Beach"

When were you made aware of the significance of your find?

RW: The first was clearly a dinosaur bone. The second one was a different shape, but looked like the same rock. They were so close I thought they had to be from the same dinosaur, and they were.

Two days later I went to the Dinosaur Isle museum to see what I had found. The palaeontologists' eyes lit up as soon as they saw them. They couldn't find anything like them in their exhibit. It was only after they had been properly researched that I found out it was a new species.

JL: I knew I had found a vertebrae as I have an interest in archaeology and I am quite good at spotting bones. I also knew it was a fossil.

At the museum, they were very interested in it but weren't sure what it was. They said it was the best find of the year so far. But it was when they got involved with the University of Southampton that things got more interesting and they established what it really was.

How does it feel to be linked to the discovery of this species?

RW: It's like winning the lottery. I fossil hunt all the time. Whenever I have five minutes I'll be looking through some gravel, but a dinosaur bone is the ultimate find. Gifting the bones to the museum was a bit like winning the lottery and then giving your money away, but if I hadn't they would only have had half of the bones they had to research, and I wouldn't know they were something special.

JL: It was nice to find it in the first place, but as time went on and I learned more about it, it got even more exciting. I think it's incredible that the university has the technology to identify something that we didn't even know existed. In a lifetime it is nice to have one notable find. To me all fossils are interesting to find, but to have my name against this find is exciting.

What do you like about fossil hunting?

RW: When you crack open a stone, most of the time there will be nothing in it, but when you do find something, you're the first person on Earth who's ever seen it. That's such a good feeling in itself.

JL: Ever since I was young I've liked searching. I was always digging holes in the garden. I didn't always know what I was collecting until I started fossil hunting more seriously and began learning about the geology of what I was finding. The best bit is not knowing what you're going to find. A lot of the time you don't find anything, so when you do there is a thrill.

How does this dinosaur compare to your previous finds?

RW: This was my best find in the fact that it is a new species. I have also got an ichthyosaur skull, which was a cool find. That was a reptile that swam in the sea a bit like a dolphin.

I've had many less successful searches. Once I found a shell which was probably 400 million years old. I threw it over to my son to have a look and he chucked it straight into the sea, thinking it was just a stone. No one will see that ever again.

JL: I've found marine reptile bones and various other fossil types. One of my personal favourites has been fossilised seeds. They are fascinating because they look like the seeds we have today but they are millions of years old. It's quite incredible to think that would have been the life of a new plant.

Five fantastic finds

Discovered fossils of some of the most mesmerising moments in prehistory

1 FOREVER FIGHTING
Mongolia 1971

When these dinosaurs began this fight around 80 million years ago, they probably didn't know they were fighting to the death... of them both. This fossil of a Velociraptor and a Protoceratops was discovered in a tangled scrap within the Gobi Desert's sandstone cliffs. The Velociraptor has its foot claw in the neck of the Proceratops, which is biting back at its opponent's arm. It is believed that a sudden sand flow buried them mid-fight, freezing the moment.

© Yuya Tamai

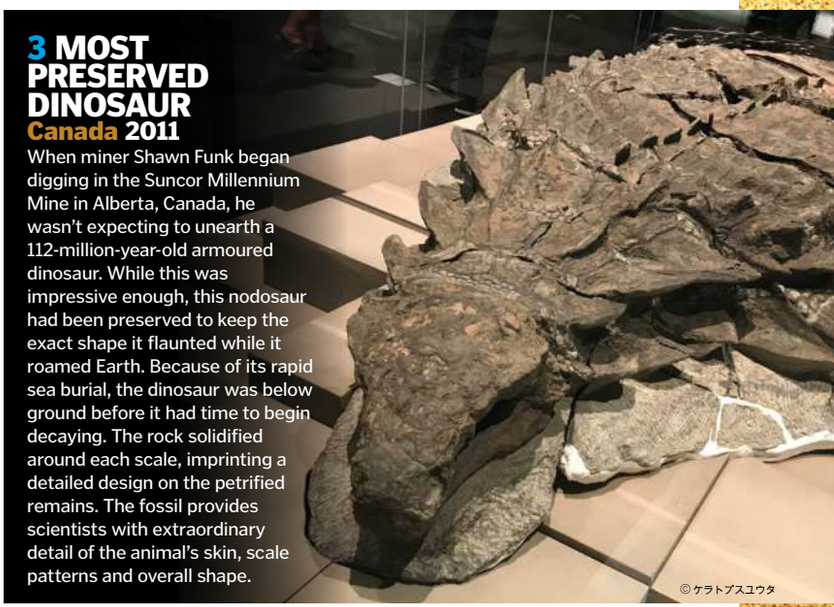
2 LARGEST *T. REX*
Canada 1991

The *Tyrannosaurus rex* is probably the world's most well-known dinosaur. Their towering stature contrasts comically with their dinky arms. After more than 20 years, research of Scotty brought this enormous species to a new level. At 13 metres long, his leg bones suggest that he would have carried a weight of 8,870 kilograms. This makes him the largest of his kind to be found.

© Kumiko

3 MOST PRESERVED DINOSAUR
Canada 2011

When miner Shawn Funk began digging in the Suncor Millennium Mine in Alberta, Canada, he wasn't expecting to unearth a 112-million-year-old armoured dinosaur. While this was impressive enough, this nodosaur had been preserved to keep the exact shape it flaunted while it roamed Earth. Because of its rapid sea burial, the dinosaur was below ground before it had time to begin decaying. The rock solidified around each scale, imprinting a detailed design on the petrified remains. The fossil provides scientists with extraordinary detail of the animal's skin, scale patterns and overall shape.



© ケラトプスユウタ

4 BIRD-LIKE BEHAVIOUR
Mongolia 1994

This small theropod, *Citipati osmolskae*, was fossilised while protecting its eggs between 83 and 66 million years ago. Spread out across its nest, just as birds often do, this find confirmed that nesting is an ancient behaviour. Uncovered from the sand of the Gobi Desert, the positioning of the body over the nest made it clear to palaeontologists that this species was guarding its young. This was the first substantial evidence showing this behaviour.

© Dinoguy2/Wikimedia Commons

© Getty

5 DINO EMBRYOS
China 2017

Finding dinosaur eggs is relatively rare, as many were soft-shelled and unlikely to become fossils. But in an even rarer case, palaeontologists in northwest China stumbled across over 200 dinosaur eggs. Within these eggs, 16 preserved embryos were found. The huge number of eggs are thought to be in the same area because the land was continuously flooded, but the dinosaurs used the same nesting site over a period of time.

Inside a palaeontologist's tool kit

What do you need to access hidden fossils?

1 Chisel
Dinosaur fossils are often found within rocks. Using a chisel and a hammer, rocks can be chipped away to reveal the inside.

2 Walkie-talkie
Some of the best finds are in extremely remote locations. If a group of fossil hunters splits up, contact with a designated base camp can be essential.

3 GPS
Keeping a record of where you are while looking for dinosaurs adds an element of safety. It is also ideal for documenting the exact location of the find.

4 Pointed-tip rock hammer
This tool is designed for use on hard rock. The flat end is used to crack open the rock and see inside without damaging any potential fossils within. The pointed end is used to dig a sample of the rock to analyse its mineral components.

5 Small probes and chisels
Accessing fossils can be a delicate procedure, requiring these small utensils. Fine-pointed picks work to uncover small fossils.

6 Dust brush
If fossils are covered in rock debris and dirt, soft brushes are a perfect way to reveal them without causing damage.

7 Swiss army knife
Compact and containing an assortment of small tools for every job, swiss army knives can be used to manipulate the rock on small samples.

8 Vinac
This solution of polyvinyl acetate adds a preservative coating to fossil finds. To stabilise dinosaur bones and stop them from breaking, they can be coated in vinac. The thin solution can be easily removed in a fossil laboratory later on.

9 Pens and bags
Fossils aren't always uncovered in one piece, with many found fragment by fragment. Plastic bags can hold pieces of a fossil together while you can use a pen to document how and where they were found, for future reference.

10 Measuring tape
Recording plenty of information about a fossil and its finding place is useful when it comes to researching the find. Measuring the distance between two found fossils can be useful in determining the likelihood that the bones are from the same animal.

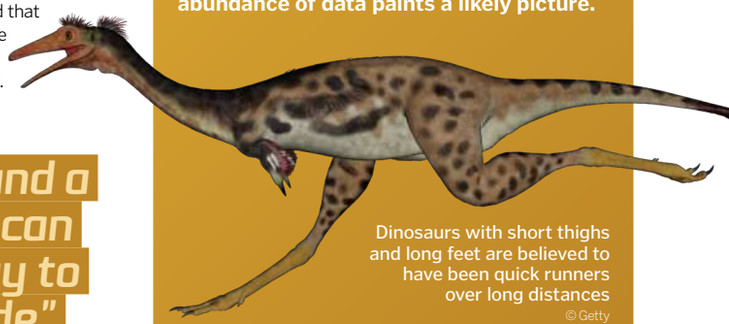
"Using a chisel and a hammer, rocks can be chipped away to reveal the inside"

Extinct behaviour

Fossils can provide incredible details about dinosaurs' anatomy and what they looked like, but what can they teach us about their lifestyles? These limited remains don't tell us everything, often leaving scientists guessing about the colour of their scales and the sound of their roars. But when it comes to their behaviour, palaeontologists can analyse data from the fossils' locations and shapes of their features to link them to possible behaviours.

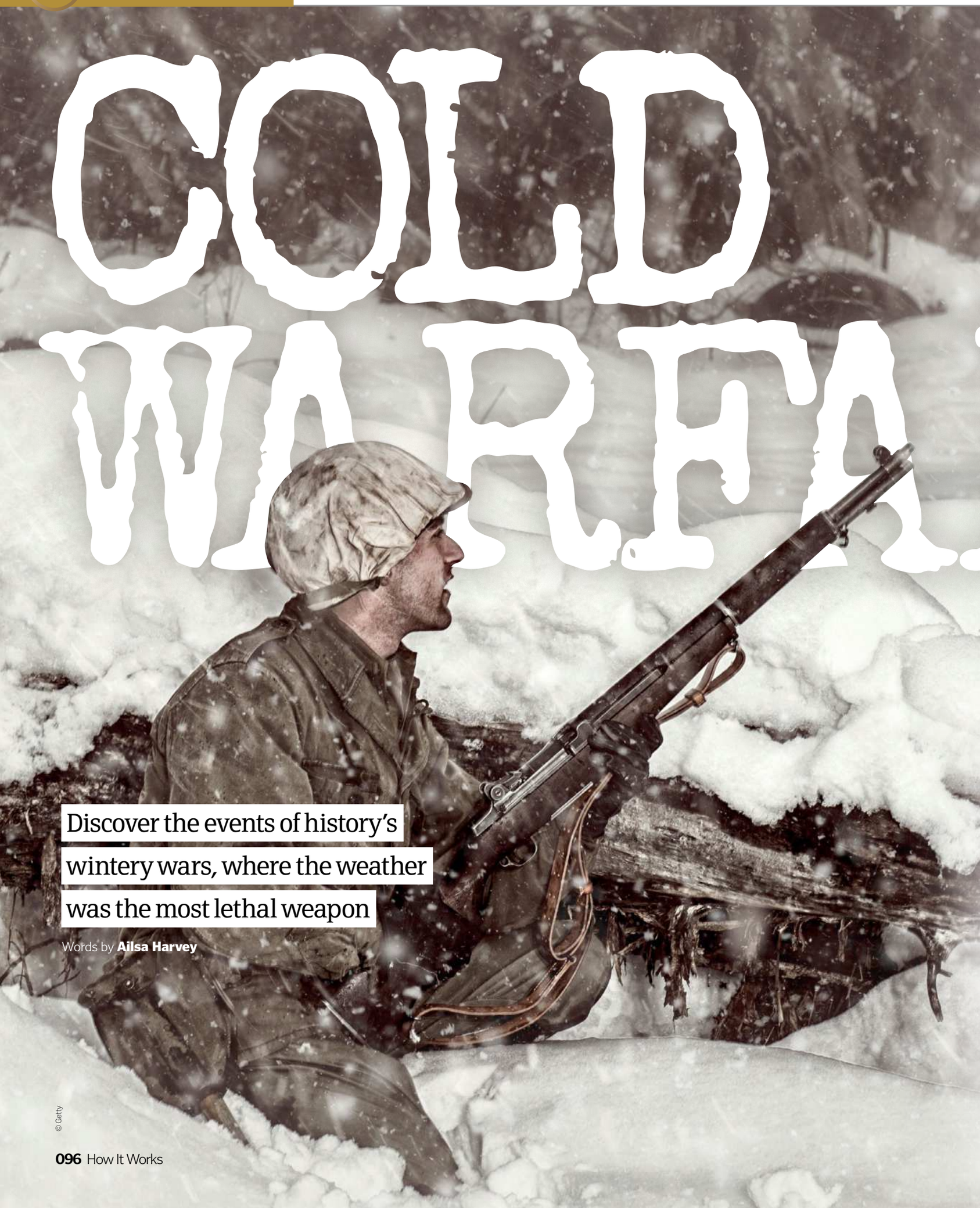
The size and shape of a dinosaur's teeth would have adapted to suit their diet, with long, sharp teeth indicating an animal that feasted on the meat of other animals. In some of the rarest fossils the contents of the stomach have been preserved – an even clearer answer to what was eaten.

When there is a combination of features all suiting a particular behaviour, this cements the hypothesis further towards certainty. Scientists can find clues in the structure of claws, fingers, wrists, joints and backbones that benefit a dinosaur's ability to dig. When all of these features are present, this abundance of data paints a likely picture.



Dinosaurs with short thighs and long feet are believed to have been quick runners over long distances

COLD WARFA



Discover the events of history's wintery wars, where the weather was the most lethal weapon

Words by **Ailsa Harvey**

RE

How do we cope when temperatures fall far below zero, mighty snowstorms sap our strength and frost-covered floors knock us from our feet with surprising ease? Just stepping outside in extreme weather can feel like a fight in itself sometimes. But how would you manage if you were forced to spend hours in these numbing conditions? Physically, the human body begins to shut down after long periods of time in very low temperatures, as our internal heat becomes compromised. In fact, if our core body temperature drops by just two degrees Celsius, we can begin to experience early signs of hypothermia.

For those who fought in some of history's coldest wars, there was no option to step back indoors. Their lives were in danger from two major threats. As their bodies were battered by the frosty conditions, they needed to retain the strength to dodge the wall of weapons being launched towards them. The only way to warmth was to eliminate the human threat before them.

As much as the cold has been a hindrance to some armies, the changing properties of frozen landscapes could sometimes be used to their advantage on the battlefield. For those fighting on their home turf, the experience of navigating icy ground allowed them to focus on the fight. In other cases, poor visibility benefited defence, like a natural smoke bomb. From the mid-storm scheming of the Middle Ages to the fight against frostbite in 20th-century warzones, these are some of history's most bitterly cold battlefields.

As Russian troops retreated, Napoleon's cannons broke the ice covering the frozen Satschan ponds, drowning soldiers
© Alamy

Freezing fog of Austerlitz

2 DECEMBER 1805 MORAVIA, AUSTRIA

In this battle of the War of the Third Coalition, French military leader Napoleon emerged triumphant. What did he do to attain this result? He incorporated the difficult weather conditions that surrounded him into his attack: instead of waiting for better visibility, he used this weather to his advantage. Amid the sub-zero fog, his tactic was to confuse the Russian and Austrian forces, whose troops outnumbered Napoleon's French army by over 20,000 men.

By pretending to retreat from the small town of Austerlitz, Napoleon made it appear that their side was weak. He planned to convince the allied Russian-Austrian armies to move into an area of dense fog. When the enemy was in place, Napoleon's troops returned to the area to attack their surprised targets, charging and reemerging from the winter fog.

This painting depicts the aftermath of the Battle of Eylau
© Alamy

The Eylau snowstorm

7 TO 8 FEBRUARY 1807 EYLAU, EAST PRUSSIA

By 1807, Napoleon was on a winning streak, but the Battle of Eylau provided a bitter end to his successes. While he was expecting another victory, he wasn't prepared for the snowstorm that encased the skirmish. In this 14-hour battle against Russia and the Prussians, the violent storm significantly reduced visibility so that his troops could only see soldiers standing immediately before them. Following a plan became difficult as every man fought for their survival.

However, surviving the fight didn't necessarily mean surviving the day. After the bloody battle, many of those wounded were left to freeze to death before they could be recovered. Temperatures continued to drop, and the attack persisted until after nightfall. When both sides were too exhausted to continue, they halted the fighting.

Battle on the Ice

5 APRIL 1242 LAKE PEIPUS, RUSSIA

If you've ever attempted to walk on a sheet of ice, you'll know how this frozen layer can upset your coordination performing even the simplest tasks. During a life-or-death contest of strength and skill, balance and perfect foot placement becomes a much more vital goal.

During the battles of the Northern Crusades, the German Teutonic Knights fought Russian Prince Alexander Nevsky's troops. The German troops, along with their allies, followed Catholicism and opposed the Orthodox Christian views of Russian leader Alexander Nevsky. In order to guarantee their win, the Russian soldiers led their enemy onto frozen Lake Peipus. Fighting on this solid lake required a whole new set of skills, and proved to be a ruthless test of endurance for the majority of the soldiers. The unlikely choice of battlefield is what gives the confrontation its name: the Battle on the Ice.

The icy strategy

How did Nevsky carry out this slippery manipulation?

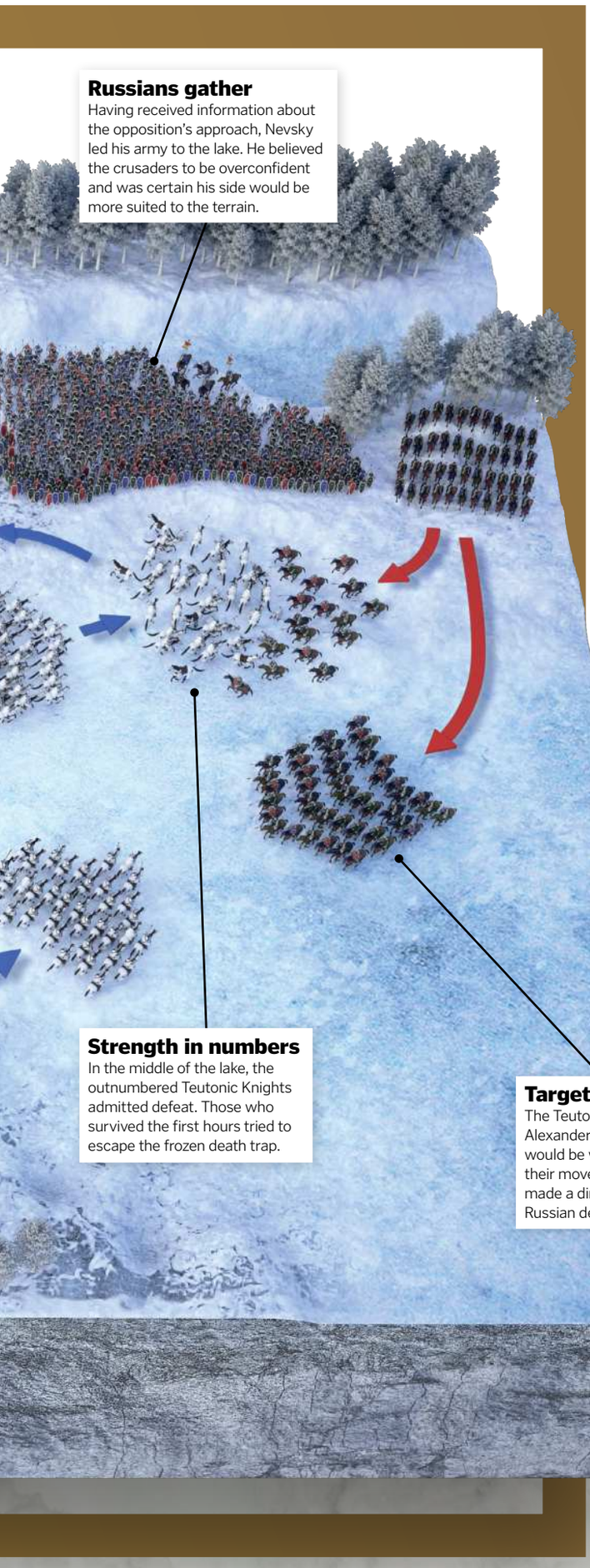
Backup
After two hours of intense combat while wrestling with the slippery surface, Nevsky ordered his backup troops to enter the lake. Having saved their strength for the initial fight, Russia had a huge advantage over the exhausted crusaders.

Danes retreat
The new wave of Russian men onto the lake was the last straw for some crusaders. The Danes, closest to the fresh arrivals, turned to exit the lake and search for more stable ground.

Teutonic Knights enter
2,600 allied troops containing soldiers from Germany, Estonia and Denmark marched towards the frozen Lake Peipus in an attempt to catch the Russian army.

Hopeful charge
All the allied fighters entered the uneven surface of the lake at the same time. The knights charged ahead at full force, while the rest followed on foot.

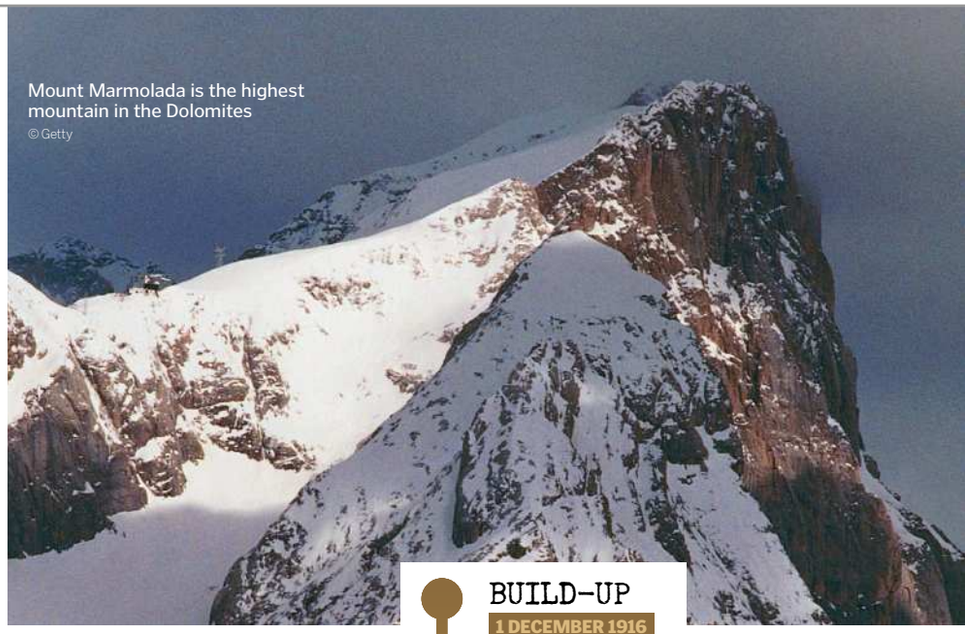
Escape the ice
Eventually, the remaining allied crusaders abandoned the lake. Nevsky's win in this battle set geopolitical boundaries that still remain today, such as across the frequently frozen lake where the Estonia-Russia border lies.



Russians gather
Having received information about the opposition's approach, Nevsky led his army to the lake. He believed the crusaders to be overconfident and was certain his side would be more suited to the terrain.

Strength in numbers
In the middle of the lake, the outnumbered Teutonic Knights admitted defeat. Those who survived the first hours tried to escape the frozen death trap.

Targeting Nevsky
The Teutonic Knights had one main goal – to kill Alexander Nevsky. They knew that the rest of the army would be weakened without him, but unfortunately their move was predicted. As a formation of troops made a direct charge against the Prince, the prepared Russian defence mirrored their move.



Mount Marmolada is the highest mountain in the Dolomites
© Getty

The events of 'White Friday'

MOUNT MARMOLADA, ITALY

High in the snow-packed Alps, a series of attacks took place surrounding the Austrian-Italian border during World War I. As Austria and Italy's armies climbed higher to reach better positions and continued to fire their weapons into the snowy peaks, the danger level escalated. But one particular day saw a killer with much more power than enemy fire. In mid-December 1916, a series of deadly avalanches swept away the lives of at least 2,000 soldiers.

BUILD-UP
1 DECEMBER 1916

From the beginning of the month, the summit of the mountain had gained between 8 and 12 metres of piled-up snow. Observing the accumulation, Austro-Hungarian commander Captain Rudolf Schmid demanded troops' relocation due to a potentially larger threat. His superiors, situated in the safety of their heated offices, denied this request.

OUT OF CONTACT
5 DECEMBER 1916

Eight days before White Friday, the weather caused major disruptions to telephone lines. Without communication, both sides were low on supplies and unable to contact their bases for assistance.

HEAVY SNOWFALL
6 TO 12 DECEMBER 1916

The week prior to White Friday saw persistent heavy snowfall. This only added to the build-up to a fatal avalanche.

AUSTRIA'S BARRACKS ARE BURIED
13 DECEMBER 1916 (MORNING)

At 05:30, 200,000 tonnes of snow hurtled down the slopes and filled the Austrian soldiers' barracks. Destroying everything in its path, the wooden buildings and the 332 people occupying them were instantly crushed. Only 40 bodies were recovered from the snow, and only a few survived the event, including Captain Schmid.

ITALIAN BASE BURIED
13 DECEMBER 1916 (EVENING)

Later that same day, a second avalanche erupted from the mountains above the Italian military base. This killed hundreds more, but this was not the end of the war's avalanches. These events continued throughout the rest of December, bringing casualty numbers up to their thousands.

INFLUENCING TACTICS
DECEMBER 1916

It's reported that throughout December, later avalanches were used tactically. Their destructive ability to doom large numbers was displayed in the early avalanches, so some soldiers would aim for weak spots of snow, firing their weapons to purposefully trigger avalanches above their enemies.

WWII's coldest conflicts

BATTLE OF THE BULGE

In a last major offensive towards the end of the war, Germany aimed to split up the Allied forces. Amid the icy blizzards, visibility was poor and temperatures plummeted, freezing weapons and tanks.

American soldiers during the Battle of the Bulge
© Getty

Battle of Stalingrad soldiers on the front line
© Getty

BATTLE OF STALINGRAD

Around 2 million people lost their lives as Germany attempted to take the city of Stalingrad. Becoming one of the bloodiest battles in history, the freezing temperatures added to the death toll. Most days the temperature was a harsh -20 degrees Celsius, reaching a low of -30 degrees Celsius.

LAPLAND WAR

Finland and Nazi Germany fought for power over the Lapland province during the winter, when temperatures ranged from zero to -30 degrees Celsius.

German soldier preparing weapons during the Lapland War
© Getty

Operation Silver Fox took place in Karelia, Finland
© Alamy

OPERATION SILVER FOX

The German military's main aim was to capture a Soviet port in Finland. This proved unsuccessful, largely due to the unforgiving weather. Ice and snow had frozen over most of the land, and with only a few roads available to travel, their route to the port was limited. An overall lack of preparation meant that the defence had the advantage and won.

US troops travelling across the island of Attu
© Alamy

BATTLE OF ATTU

Japan gained control of the island, getting used to the drastic difference in climate compared to their homeland. US soldiers didn't anticipate the sudden wind storms and fog-covered peaks. Early on, more American soldiers fell victim to the weather conditions, dying from frostbite and trench foot rather than from Japanese attacks.

Battle of Towton: where weather was in command

29 MARCH 1461 YORKSHIRE, ENGLAND

Battling the blizzard

How a relentless snowstorm impacted England's bloodiest fight

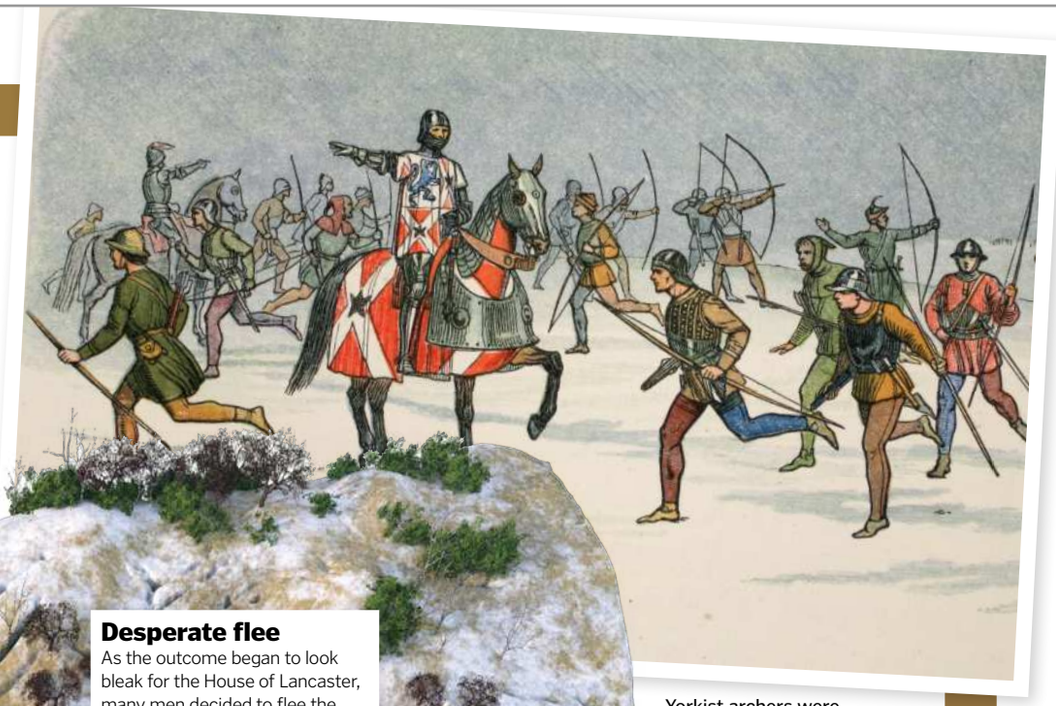
Chosen location
65,000 soldiers met for battle on a large open field between the villages of Towton and Saxton in North Yorkshire.

Road to London
The attack was launched beside the road that connected Towton and London. As the road led behind York's troops, wind was able to pick up speed over this flat land, in the direction of the Lancastrian army.

Saxton village
The Yorkist army travelled to a village around 1.5 miles from Towton, where Lancaster troops were stationed.

Duke's troops
It wasn't just the fact that he took advantage of the wind that helped York win. The Duke of Norfolk, John Mowbray, arrived during the battle with his own troops. The extra archers added to the arrows raining down upon the enemy.

During the Wars of the Roses, multiple brutal battles were fought between the houses of York and Lancaster, with both sides eager to gain control of the English throne. The coldest of the wars' conflicts played out near the small village of Towton. Lancastrian King Henry VI denied Yorkist Edward IV his succession to the throne, and it was this argument that was to be settled in the bitter conditions of this battlefield.



Yorkist archers were ordered to fire into the wind

Red river
The River Cock flowed red with blood and filled with dead bodies as York continued to hunt down the retreating men.

Desperate flee
As the outcome began to look bleak for the House of Lancaster, many men decided to flee the battlefield. Some took the risk of removing armour in order to run more easily across the icy terrain.

Wind advantage
As the snowstorm continued, the wind carried snow and the Yorkist's arrows across much longer distances than the Lancastrians could achieve.

Desperate charge
Being outside in the wet weather for days prior to the fight caused the armour on many men to rust. Those who didn't treat their steel equipment daily with sand and vinegar were forced to fight head-on without armour, dying due to a lack of protection.

Central clash
Lancaster had about 5,000 more men than York, but limited as they were by the weather conditions, they ended up losing their upper hand. Their vision was impacted by the snowy headwind as they struggled to hold their territory on frozen ground.

Towton
While in Towton, Lancaster's troops postponed the battle by one day, giving a chance to gather more men.

Sunken cities

Explore these submerged settlements to discover why they didn't survive the test of time

Words by **Nikole Robinson**

Humans need water to survive, and so access to this precious natural resource has been an important factor in deciding where we have made our homes throughout history. Building near rivers, lakes and springs gave early settlements access to clean water for domestic and agricultural use, and the availability of fish was a reliable food source. Travelling by boat also became an easy way to navigate the land more quickly, allowing our species to migrate to new areas. As humans spread across continents and populations boomed, trade between civilisations became more frequent. Coastal settlements allowed for larger vessels to come and go, increasing trade and therefore the local economy, with many more port towns being built as a way to access rare goods and riches.

But the waterfront isn't always a safe place to settle. With little protection from flooding, natural disasters such as earthquakes and tsunamis, bad weather and changing sea levels can all easily destroy in a day what has taken people hundreds of years to build. Water can claim the land, buildings and human lives. Here we dive into some of the lost civilisations now deluged beneath the depths.

© Wiki/nihaopaul

CHINA

Lion City

DATE SUNK: 1959

This valley in Zhejiang Province was purposely flooded as part of the Xin'an River Dam project to generate hydroelectric power for the region. Submerged 25 to 40 metres below the surface of the human-made Qiandao Lake lies an ancient city frozen in time. Believed to be around 1,400 years old – though some believe certain structures are even older – the city once stood at the bottom of Wu Shi (Five Lion) Mountain, which is now also partially submerged. Rediscovered in 2001 on a diving excursion, the city is a well-preserved relic of its time, with many intricate carvings of dragons, phoenixes and lions surviving in all their glory on wooden arches. Temples, pagodas and other structures remain intact thanks to the purity of the water, allowing archaeologists a window into the architectural design of ancient China.

© Getty

The reservoir is fittingly known as Thousand Island Lake

© Getty

THE NETHERLANDS

Saeftinghe

DATE SUNK: 1584

Now a swamp known as the Drowned Land of Saeftinghe, this was once a prosperous place. In the 13th century the marsh was drained so that the fertile land could be built on, and dikes were raised around the reclaimed land to protect it from floods. Much of the land around Saeftinghe was lost in the All Saints' Flood of 1570, but the final blow came during the Eighty Years' War in 1584. Dutch soldiers fighting in the war for independence were forced to destroy the last dike barrier while defending Antwerp, allowing the waters of the Scheldt to take over the town. A local legend tells a slightly different tale, however, blaming the 1570 flood on the wrath of a mermaid held captive by the townsfolk. Today the settlement is buried under layers of sand and clay, though bricks have been recovered that could have belonged to an abbey taken by floods.

All that remains of Saeftinghe is marshland, frequently covered by tumultuous tides

© Alamy

"Dikes were raised around the reclaimed land to protect it from floods"

AR ZONE!

JAMAICA

Port Royal

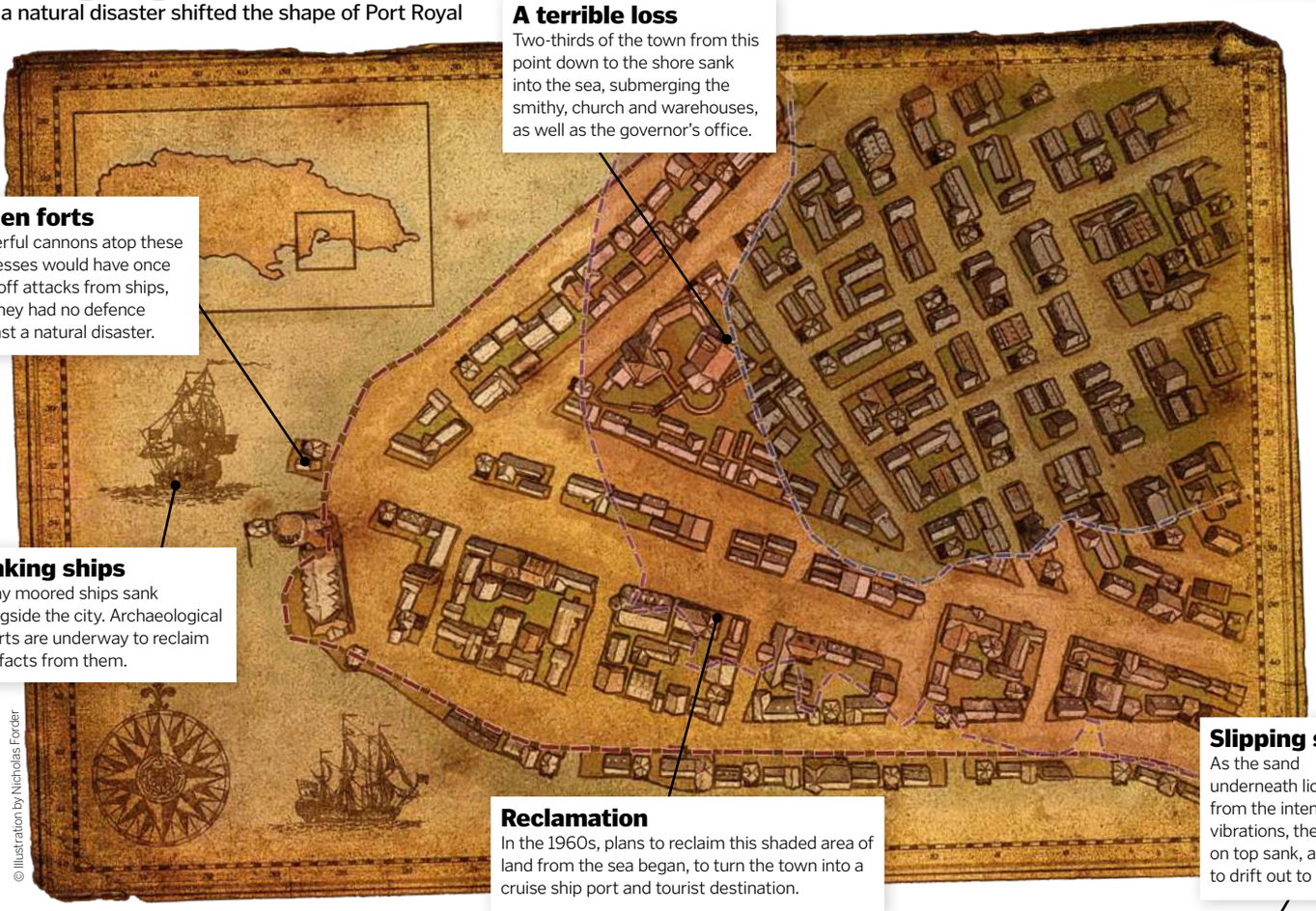
DATE SUNK: 7 JUNE 1692

The Caribbean pirate haven of Port Royal was known as 'the wickedest city on Earth' before a devastating earthquake and the tsunami that followed in its wake cast two-thirds of the town below the waves. The intense shaking liquified the sand beneath the 2,000 or so brick buildings, which were displaced and appeared to flow out to sea. Of the estimated 6,500 inhabitants of the town at the time of the disaster, 2,000 are thought to have perished in the earthquake and tsunami. A further 3,000 were to meet their end from injuries and disease in the aftermath.

Artist Jan Luyken's impression of the disaster

Changing shorelines

How a natural disaster shifted the shape of Port Royal



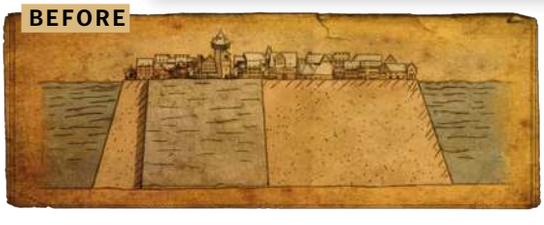
A terrible loss
Two-thirds of the town from this point down to the shore sank into the sea, submerging the smithy, church and warehouses, as well as the governor's office.

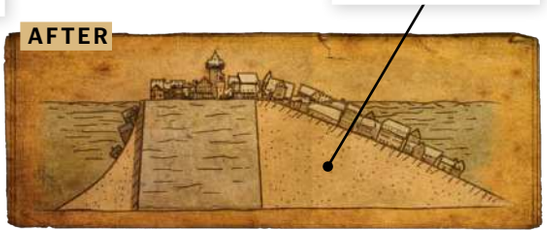
Fallen forts
Powerful cannons atop these fortresses would have once held off attacks from ships, but they had no defence against a natural disaster.

Sinking ships
Many moored ships sank alongside the city. Archaeological efforts are underway to reclaim artefacts from them.

Reclamation
In the 1960s, plans to reclaim this shaded area of land from the sea began, to turn the town into a cruise ship port and tourist destination.

Slipping sand
As the sand underneath liquified from the intense vibrations, the buildings on top sank, appearing to drift out to sea.





AR ZONE! SCAN HERE

GERMANY

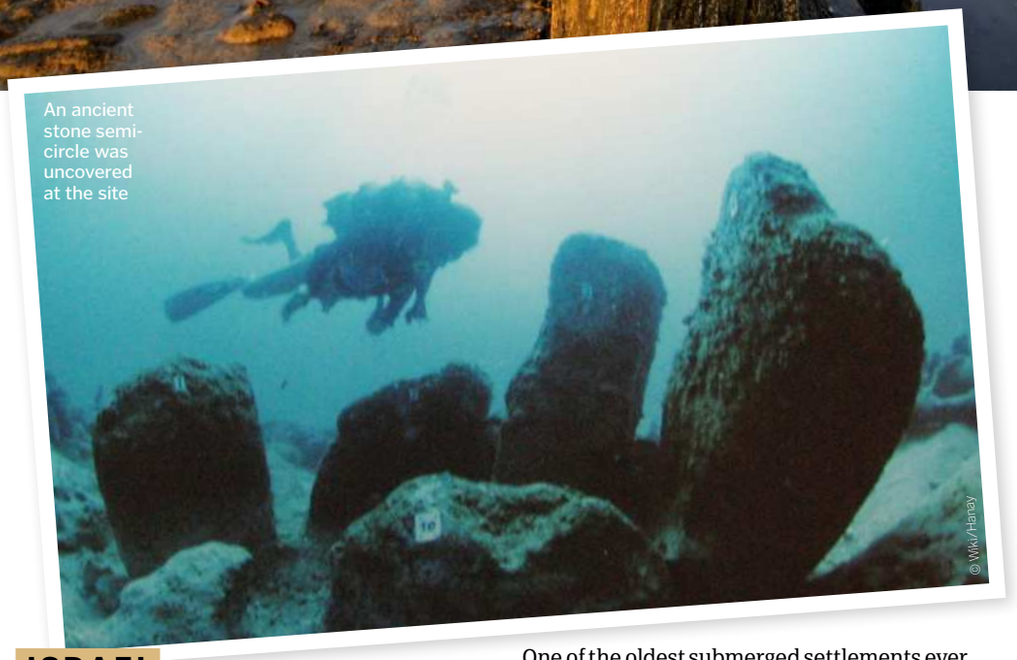
Rungholt

DATE SUNK: 16 JANUARY 1362

Long considered to be just a legend, the exact location of Rungholt remains unclear, though artefacts have been found in the Wadden Sea that hint at its existence as a trading port. Saint Marcellus' flood, also known as the 'Great Drowning of Men', is thought to be the culprit behind the town's disappearance. Storm tides caused by an extratropical cyclone swept in from the North Sea, decimating the coasts of the British Isles, the Netherlands, northern Germany and Denmark and causing deaths in thousands.

The area suspected to have hosted Rungholt is mostly salt flats now

© Getty



An ancient stone semi-circle was uncovered at the site

© Wiki/Haraiy

ISRAEL

Atlit Yam

DATE SUNK: 6300 BCE

This Neolithic village lies 8 to 12 metres beneath the Mediterranean, hidden for over 8,000 years until marine archaeologist Ehud Galili was surveying the sand for shipwrecks in 1984.

One of the oldest submerged settlements ever discovered, careful excavations have revealed rectangular houses with hearths and the remains of a dry-stone well. One of the most interesting finds was a megalith structure – similar to Stonehenge – built around a spring, made of seven huge stones weighing around 600 kilograms each, while burial sites and human remains have also been unearthed. One study suggests that a tsunami is likely to blame for the abandonment of the settlement.

ITALY

Baiae

DATE SUNK: 16TH CENTURY

Once a Roman spa town known for debauchery, underground pressure causes the land in the area to rise and fall, and much of its ancient history lies just six metres below sea level. Of note are the underwater remains of the Pisonian Villa and the statue-adorned Sunken Nymphaeum of Emperor Claudius.

© Getty

GREECE

Pavlopetri

DATE SUNK: 1000 BCE

Uncovered in 1967, analyses of building materials date these ruins to be around 5,000 years old. Existing above ground for 2,000 years before it was likely sunk by earthquakes, the layout of the town has been preserved perfectly four metres below the waves, with its streets, buildings and tombs eroded by age but clear to see – at least 15 buildings have been identified.

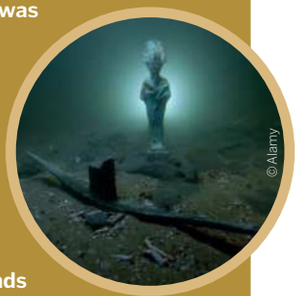
© Alamy

EGYPT

Thonis-Heracleion

DATE SUNK: 6TH OR 7TH CENTURY CE

Northwest of Alexandria on the Nile Delta, this was a popular trading port before tremors weakened the land and dragged it below the brine. A giant six-tonne statue of the Nile god Hapy is one of the most significant finds from the ruins.



© Alamy

Submerged secrets

There are many interesting things hidden under the water around the world

TITANIC

The most famous wreck in the world is deteriorating at the bottom of the Atlantic after its fateful meeting with an iceberg over 100 years ago.

DOLCHISTE

On the northern side of the Turkish island of Kekova, the partially submerged ruins of this town are often visited by boat tours.

LAKE MICHIGAN

Shipwreck searches turned up a stone carving of a mastodon and a Stonehenge-like structure about 12 metres below the surface of this Great Lake.

DUNWICH

Now a quaint village in Suffolk, England, in Anglo-Saxon times this was a major trading port before it was destroyed by storms.

GRÜNER SEE

Green Lake floods every year due to snowmelt from the Hochschwab Mountains, becoming a popular spot for divers due to the surreal experience.

CENOTE ANGELITA

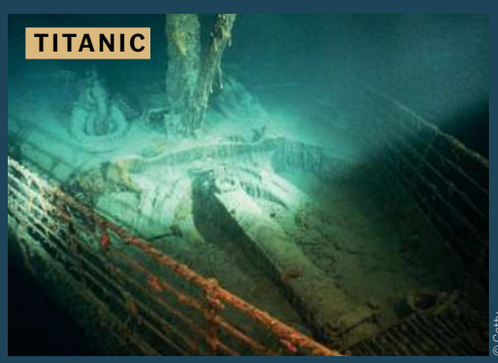
This cave has an 'underwater river'. This eerie effect is created by hydrogen sulphide released from organic matter separating the fresh and saltwater.

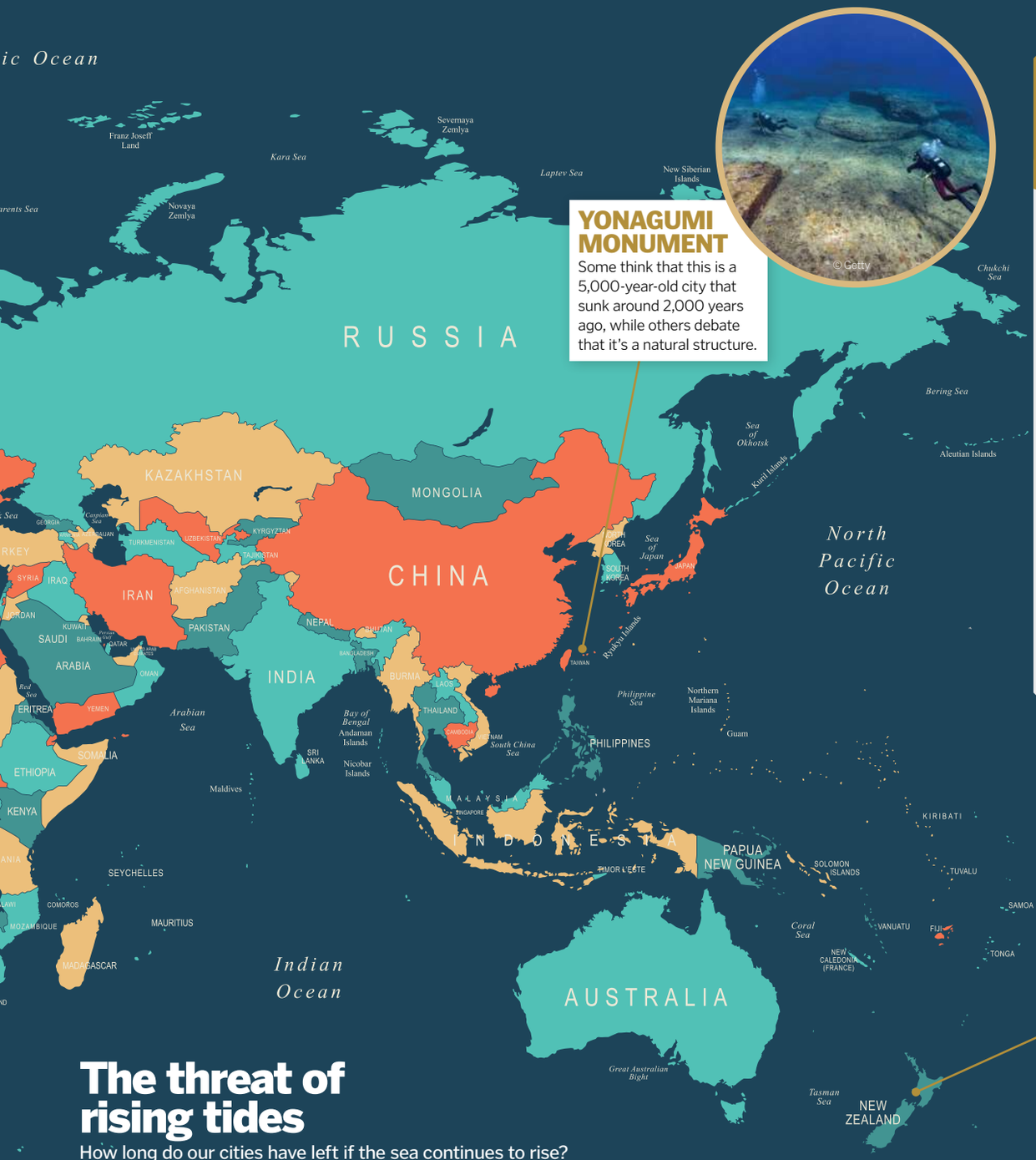
APOLLO 11

In 2013, Jeff Bezos spearheaded an expedition to retrieve parts of the Saturn V rocket that launched astronauts to the Moon from the seafloor.

NEAPOLIS

A massive storm in 2013 revealed strange stone shapes in the seabed. They were identified as a Roman port town, Neapolis, sunk by an earthquake in 365 CE.





© Getty

YONAGUMI MONUMENT

Some think that this is a 5,000-year-old city that sunk around 2,000 years ago, while others debate that it's a natural structure.

5 FACTS ABOUT UNDERWATER ODDITIES

1 A window below
Glass-bottom boat tours are popular in Pavlopetri, Greece.

2 From pirates to cruises
The first cruise ship in over 40 years docked at Port Royal in January 2020.

3 Taller than Everest
Mauna Kea is the tallest mountain at 10,211 metres, but more than half is below sea level.

4 Sunken treasure
The San José galleon wreck holds treasures worth billions.

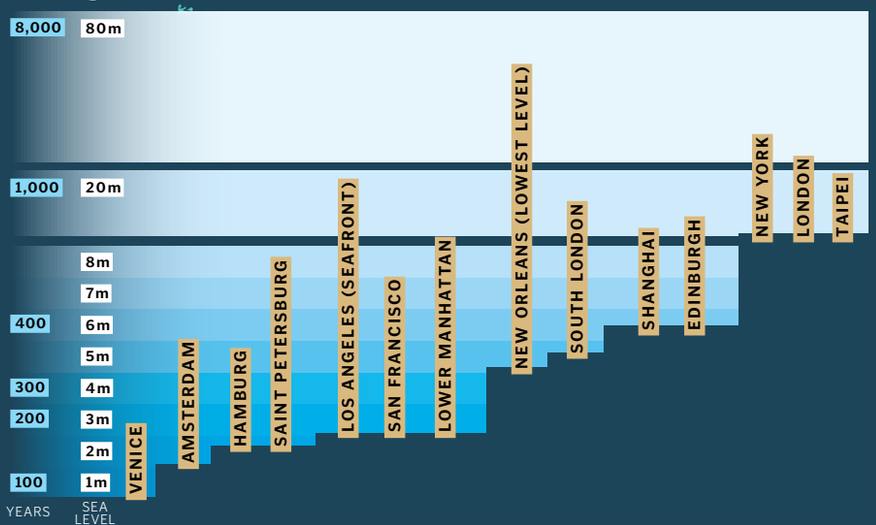
5 Sea level rise
Average sea levels have risen 23 centimetres since 1880.

LOST CONTINENT

The continent of Zealandia is mostly submerged in the South Pacific. Ball's Pyramid is one natural structure that breaches the surface.

The threat of rising tides

How long do our cities have left if the sea continues to rise?




© Wiki/Jill Bruce

NINJA VS SAMURAI

How changes in Japanese society gave rise to warriors trained in specialised arts

Words by **Nikole Robinson**

© Getty

In 646, the Taika Reforms united Japan into a state ruled by an imperial government under an emperor. Land was redistributed, and heavy taxes were imposed. These taxes meant that many farmers had to sell their land and work under others, and as a result wealthy landowners gained more power, becoming lords who answered only to the emperor. To protect their wealth, they began to hire mercenaries and employ family members as guards, triggering the age of the samurai.

These early samurai – meaning 'one who serves' – would collect taxes, threaten those who wouldn't pay up and defend their lord from rivals who might look to expand and take over their assets. However, their importance in society didn't really take shape until the Heian period, between 794 and 1185, when imperial power began to decline. The emperor's influence was lost outside of the capital, and civil wars began to break out across the county. The warrior class now played a huge role in society, and local lords began to amass personal armies in the struggle for power.

While the two sons of Emperor Toba fought over what little imperial power remained in the latter half of the 12th century, two powerful samurai and their clans were fighting their own battles. Though Taira Kiyomori's clan would be victorious at first, seizing control of Japan and establishing the first samurai-led government, after his death the Minamoto clan would strike back in the Genpei War of 1180. After their victory, the head of the clan Minamoto Yoritomo established the Kamakura shogunate, turning Japan into a military dictatorship, but allowing the emperor to remain a figurehead.

Under military rule, samurai had more power than ever before, though they were still in service to their lords, who became known as daimyo. The new enemy became the Mongol Empire, a horde of nomadic tribes who had already conquered China. With the weather and seas on its side and samurai from all over the country fighting to repel the foreign forces, Japan

© Getty

Samurai swords were masterfully crafted by experienced blacksmiths

Master of arms

As samurai gained status it became customary to carry two swords in a practice called daisho: a smaller blade called a wakizashi was used in close combat or cramped spaces. When a longer reach was needed in combat, a samurai would use a long, straight-headed spear called a yari. These could puncture armour with a thrust, and were also used in mounted combat. Often fighting from horseback, the art of archery (kyujutsu) was another vital skill for any samurai, who used huge, two-metre asymmetrical bows (yumi). After the introduction of firearms to Japan, which they called tanegashima, it took a while for them to be widely adopted, with experienced archers still more deadly with bows than these advanced weapons. Once the design of guns had been improved, samurai began to use them as part of their arsenal.

© Wiki/Kusakabe Kimbei

Samurai would master fighting with yumi and ya (arrows), katana and yari

© Wiki/Akiyoshi Matsuoka

The woven basket of a komuso monk made a good face covering

kept the invaders at bay. However, the Kamakura shogunate was unable to offer much reward to the samurai leaders who had come to the country's defence, and soon its grip would begin to loosen.

In the 1400s the entire country was plunged into civil war once again, with the daimyo all vying for power using the strength of the samurai in their service. This 100-year conflict would be dubbed the Warring States period, and would see the status of the most powerful samurai equal that of nobles, with their standing able to pass down to their children.

During this brutal period, powerful daimyo would also employ more clandestine tactics, hiring shinobi warriors – better known as ninjas – for sneak attacks and sabotage. In stark contrast to the samurai and their newfound nobility and code of honour, ninjas were low-class citizens trained in specialised skills and stealth, making them the perfect spies. Because of their secretive nature, it's hard to say when exactly the art of ninjutsu began to develop and when ninjas were active in warfare, but many of them can be traced to the Iga and Koga regions of Japan.

The eventual reunification of Japan would start with the powerful daimyo Oda Nobunaga, whose army defeated other influential warlords and overthrew the Ashikaga shogunate. Seeing ninjas as a huge threat, he first defeated and scattered the Koga shinobi, then launched a massive offensive on the Iga clan. Decimating them in open combat, many remaining ninjas would end up in the service of Tokugawa Ieyasu, who would rule Japan as shogun from 1603.

After years of turmoil, Tokugawa ushered in a new era of peace and stability, and suddenly there was no place for the samurai or ninjas outside of the shogunate's service. Some samurai remained loyal to their lords, but rarely saw combat, while others were forced to hang up their swords and become farmers. Ninjas became more of a myth, with their exaggerated 'magical' abilities becoming legend.

AR ZONE!

Shielding the samurai

These highly decorated warriors wore heavy, plated armour and carried katanas

Menpo
Serving as protection for the face, the intricate and often demonic designs of these masks were also an intimidation tactic.

Kabuto
Protecting the head, helmets also showed off wealth and status. As samurai rose to power they became more elaborate, with maedate (front ornaments) becoming complex and ornate.

Do
Samurai armour was both sturdy and flexible. Made of metal, wood or leather plates stitched together, the wearer could move freely in battle.

Kote
Before the 12th century, only the left arm was covered to aid with archery. The style of these armoured sleeves varied greatly, as did their level of protection.

Katana
The iconic weapon of a samurai, a katana is a curved, single-edged blade with a long grip – they could be wielded with one or both hands.

Kusazuri
A four-piece, armour-plated skirt was attracted to a belt and laced to the do. This covered the thigh armour, called haidate.

Suneate
Made in the same style, colour and materials to match the kote, these were usually vertical armour plates with a cloth backing.

Waraji
Though the rest of their body was heavily guarded, samurai wore simple straw sandals on their feet over split-toe socks called tabi.

Way of the warrior

Samurai lived by a moral code called bushido

義

Justice (gi)
Sometimes called righteousness, the core of this virtue was doing the right thing, even when no one was watching, and treating all people fairly.

勇

Courage (yu)
A true warrior should be heroic, not only in combat when facing death, but in all aspects of life. A samurai would never run from battle or responsibilities.

仁

Compassion (jin)
A samurai used their strength to help others, using their power for the greater good rather than selfishness.

礼

Respect (rei)
Samurai showed respect by being polite and well-mannered to all people, including those beneath them in status.

誠

Honesty (makoto)
A samurai wouldn't lie, and needed to fulfil promises made. They were supposed to be sincere and dependable, and were therefore taken at their word.

名誉

Honour (meiyo)
Dishonour was worse than death for many samurai, who feared disgracing themselves and their families with actions that went against their virtues.

忠義

Loyalty (chugi)
Samurai needed to be counted on by the lords that they served and not betray them. They were also loyal to their families.

自制

Self-control (jisei)
A samurai was in control of what they said or did, always upholding their code of honour despite temptations and impulses.

A time of change

646
The Taika Reforms change the country to mimic Chinese culture and rule, allowing some landowners to become powerful lords.

1192
Minamoto Yoritomo becomes the first shogun of Japan, establishing the Kamakura shogunate.

Source: Wiki/Fujiwara no Takanobu

1274
Kublai Khan sends 600 ships carrying Mongol warriors to Japan. They are hit by typhoons and about 10,000 samurai called into service, who send the warriors packing.

1467-1615
The Sengoku or Warring States period. Japan is split into small regions. Daimyo fight each other for power and samurai and ninjas are active in their service.

1568
After unifying Japan and ending many conflicts, Oda Nobunaga instills Rokkaku Yoshikata as the new shogun.

Ninja strategies

Cunning and deception gave ninjas an advantage over their enemies

Assassination

Stealth allowed ninjas to get close to their targets without raising suspicion, and many daimyo feared a surprise attack. Castles used uguisu-bari flooring that would make a bird-like sound when stepped on.

Espionage

Blending in behind enemy lines, a ninja could learn about an enemy's plans or a castle's defences. Monks and priests were popular disguises for ninjas, though many simply dressed as commoners.

Arson

Gunpowder stores, armouries, warehouses and palaces were all prime targets – sometimes from afar by firing flaming arrows, or bo-hiya. Setting multiple fires would cause more chaos and confusion.

Deception and sabotage

A ninja hidden among the enemy could spread misinformation and pass on incorrect orders. They could also destroy or steal supplies, poison wells or ambush enemy soldiers.

Escape

Ninjas were so good at slipping away that it was said they could disappear through walls. They made use of nature, hiding high in trees or underwater, as well as using smoke bombs to obscure an enemy's vision while they ran or hid.

A ninja's arsenal

Specialised tools and weapons allowed ninjas to strike from the shadows

Kaginawa

Rope grappling hooks were used to scale walls, for example during castle sieges. Some ninjas used hooked rope ladders instead.

Masked identity

Allowing an assassin to remain anonymous, the head was wrapped in a zukin, while the face was covered by a piece of cloth called a fukumen.

Tanto

A short sword was easier to conceal, though some ninjas carried full swords, often choosing a disguise that would allow them to carry one without suspicion.

Tetsubishi

These small, spiked metal objects could be dropped to slow down pursuers and aid in escape. These would easily pierce straw waraji sandals.

Kusarigama

The weighted chain could be used a bit like a lasso, wrapping around an enemy's weapon or tying them up. The kama (sickle) could then be used to attack an incapacitated enemy.

Shinobi shozoku

A stereotypical ninja is shrouded in black robes. With most of their work done under cover of darkness, dark blue would actually have helped hide them more effectively.

Shuko and ashiko

With shuko worn on the hands and ashiko on the feet, spikes were driven into walls or trees to help climb them. They could also be used in hand-to-hand combat.

Shuriken

Designed in many shapes, the most commonly depicted is a star. These could be used as throwing weapons or as a small dagger in a pinch.

AR ZONE! SCAN HERE

Wiki/Utagawa Kuniyoshi

1591

Samurai are no longer allowed to farm their own land, and rice is provided by their daimyo as payment for their service.

1676

Fujibayashi Yasutake releases the Bansenshukai, a book on the ways and training of the Iga and Koga ninja clans.

1701-1702

The 47 ronin infamously avenge the death of their master Asano Naganori, after which they disband and commit seppuku, an honourable ritual death.

1876

Samurai are banned from carrying daisho and are only permitted to carry short swords. With no real place for them in society, many enter military service.

AR ZONE!

© Alamy

A sneak peek

What spaces are found within these walls?

AR ZONE! SCAN HERE

Inside 10 Downing Street

Take a tour of the UK prime minister's official abode

Words by **Ailsa Harvey**

Ever since Robert Walpole, the first person regarded as holding the power and position of a British prime minister, 10 Downing Street has been the prime minister's official residence. This came about when King George II offered Walpole the building as a gift in 1732. Walpole accepted it on the condition that it was not a gift solely to him, but to whoever held his position. To this day, the role of prime minister has come with this gift.

Signifying this tradition, the portraits of former prime ministers are placed on the wall leading up its grand staircase. The current prime minister is missing from this display, but as soon as they leave office the frames are shifted down the wall, and a new portrait is added at the top. There is no requirement for a prime minister to live within these walls, however. In fact, between 1735 and 1902, only 16 of the 32 leading statesmen – and one woman – stayed there. In more recent years many prime ministers, such as the UK's current leader Boris Johnson, chose to move into Number 11, where there is a more spacious flat.

Behind the famous, bomb-proof black door of 10 Downing Street is a mansion of around 100 rooms. The building's purpose isn't just to add comfort to the life of the prime minister, but to create a setting where some of the most important decisions can be made on behalf of the country.

Cooking for the crowds

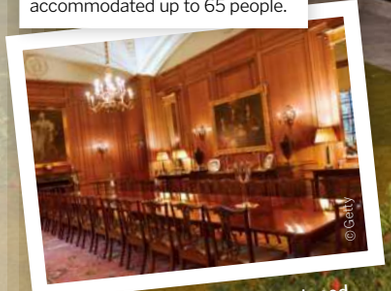
These large kitchens cater for those attending events in Downing Street. During World War II, this was one of the areas damaged by bombing.

Plentiful offices

Around 200 members of staff work for the prime minister within Downing Street. The main political office is next to the prime minister's meeting room.

A place to eat

There are dining rooms for everyday use, as well as a large State Dining Room, which has accommodated up to 65 people.



© Getty

The State Dining Room was designed in 1825 by Sir John Soane

© Getty

Guests are often shown the Pillared Room before they're seated to dine

Hosting grand receptions

This is the Pillared Room, which is used for the biggest receptions, including the signing of international agreements.

Not just Number 10

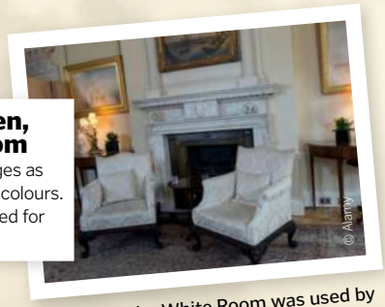
It might often be referred to as Number 10, but the prime minister's facilities actually cover more residences. The main building has been connected to the backward-facing Number 11, while Number 9 and Number 12 are also in use. 9 Downing Street is where press briefings take place. In the media room, the prime minister broadcasts to the country and the press. Number 12 is primarily used as offices for employees, and was traditionally home to the chief whip, who makes sure members of the political party attend and vote in parliament.

© Getty

A new media briefing room in Number 9 was unveiled in 2021

The Blue, or Green, or Terracotta room

Its name frequently changes as the walls are painted new colours. This space was initially used for dining in.



© Alamy

Until 1940, the White Room was used by prime ministers for privacy

Luxurious living

On the top floor there is a large flat where the prime minister can choose to live.

Appointments with the chancellor

The chancellor has the option to live in Downing Street and is assigned this area to hold informal meetings.

The chancellor's workplace

This is where the chancellor works to track and control the country's finances.

The weekly gathering

Surrounded by sound-proof walls, the cabinet meets here on a weekly basis to discuss domestic and foreign affairs.

© Getty

The Cabinet Room in 1964

Enter the den

Important decisions are often made in the prime minister's meeting room, also referred to as the 'den'.

Areas for errands

At the back of the building are garden-facing rooms for Downing Street's secretaries. These secretaries attend to the prime minister's daily needs.

Illustrations by © Nicholas Forder

TECHNOLOGY

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Floating research laboratories

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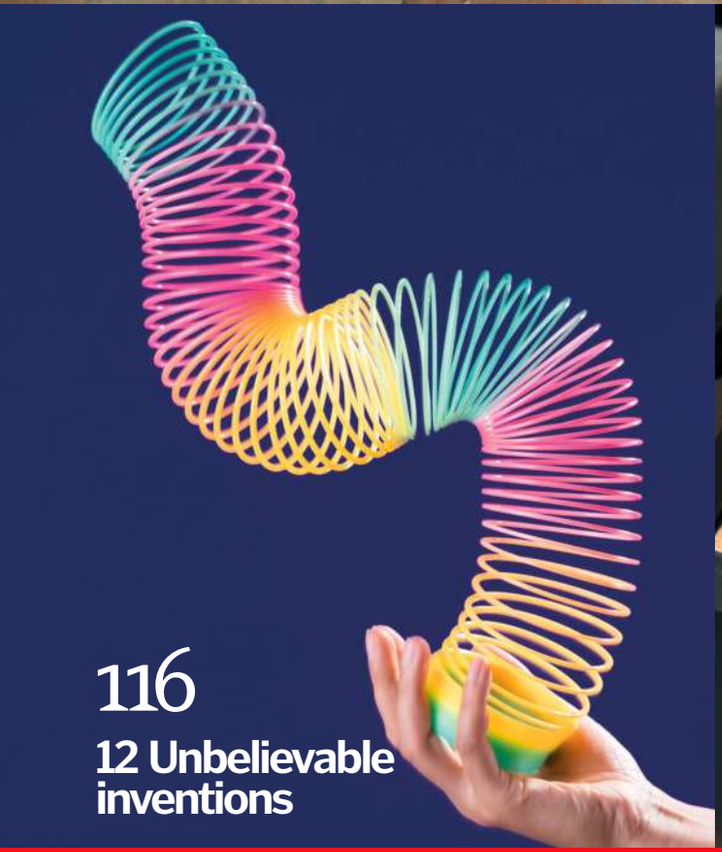
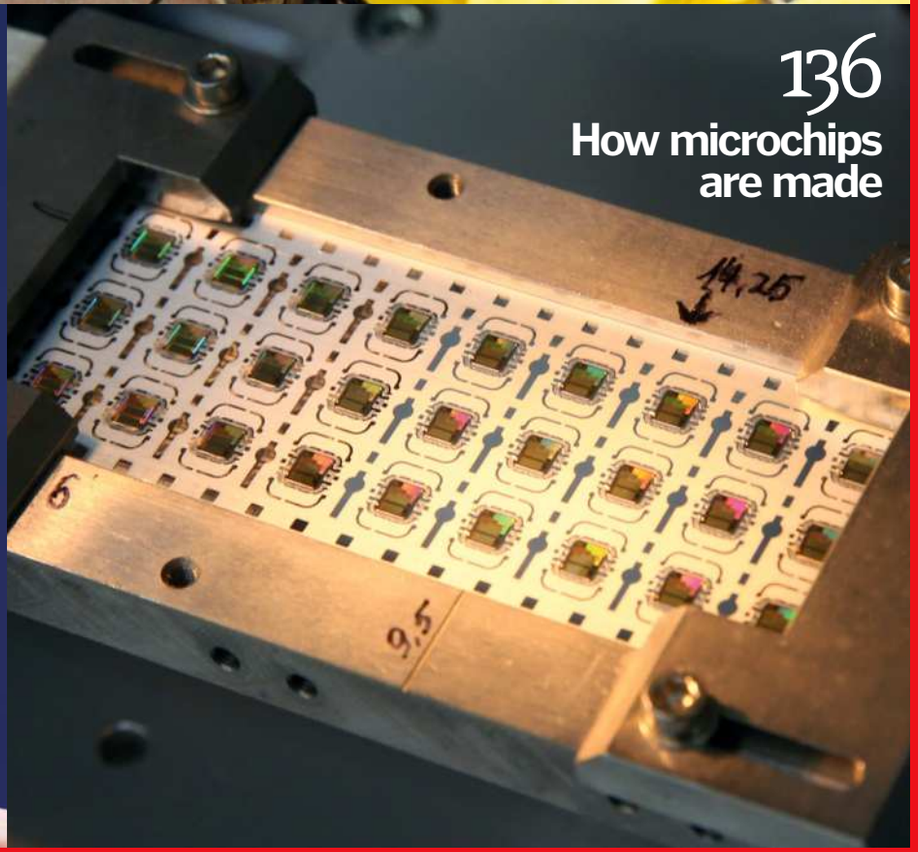
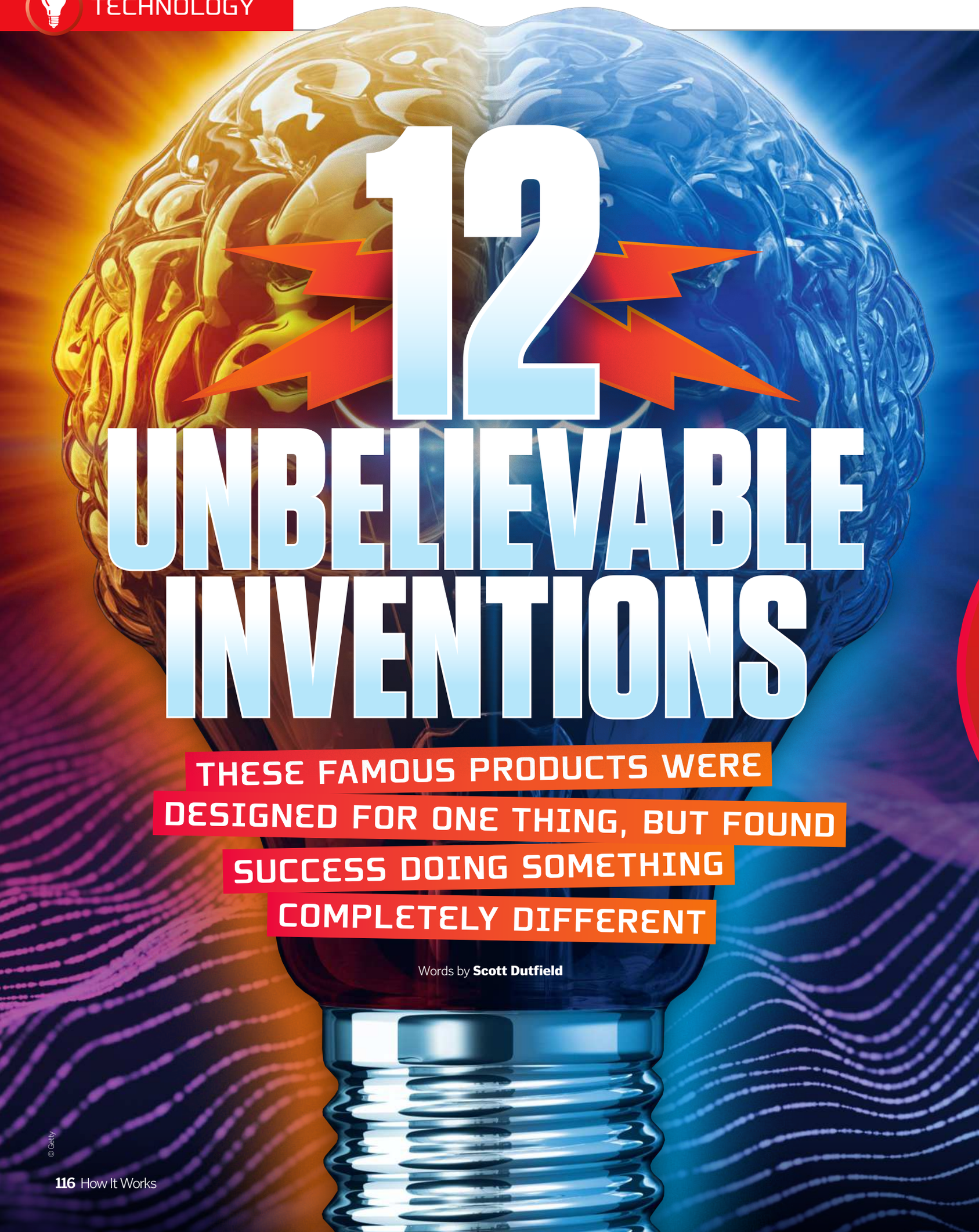
Anatomy of a rock concert

AR ZONE!



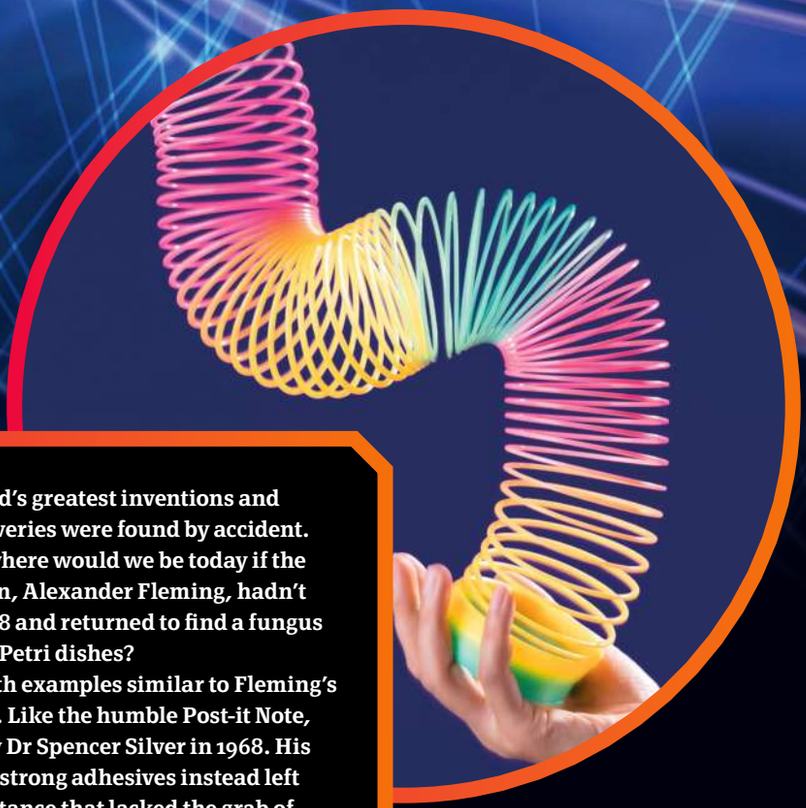




12 UNBELIEVABLE INVENTIONS

THESE FAMOUS PRODUCTS WERE DESIGNED FOR ONE THING, BUT FOUND SUCCESS DOING SOMETHING COMPLETELY DIFFERENT

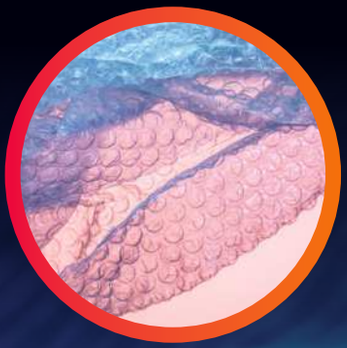
Words by **Scott Dutfield**



Some of the world's greatest inventions and scientific discoveries were found by accident. For example, where would we be today if the discoverer of penicillin, Alexander Fleming, hadn't gone on holiday in 1928 and returned to find a fungus killing bacteria in his Petri dishes?

History is awash with examples similar to Fleming's unexpected discovery. Like the humble Post-it Note, which was created by Dr Spencer Silver in 1968. His experiments with strong adhesives instead left him with a substance that lacked the grab of glue, but could stick to surfaces and peel away easily. Teflon is another product where a discovery was made by chance. In 1938, Dr Roy J. Plunkett was experimenting with different refrigerant gases, including tetrafluoroethylene (TFE). In one refrigerator the gas appeared to be missing, but upon further inspection, Plunkett found that the TFE had polymerised into a white powder called polytetrafluoroethylene (PTFE). This new substance was super slippery and had a high melting point, making it perfect for creating non-stick kitchenware.

Some discoveries were made after an invention had already hit the supermarket shelves. They're proof that just because something is created for one purpose doesn't mean it can't be used more successfully for another. Here are some of the world's most famous products with the most surprising origin stories.



THE SCIENCE BEHIND SLINKIES

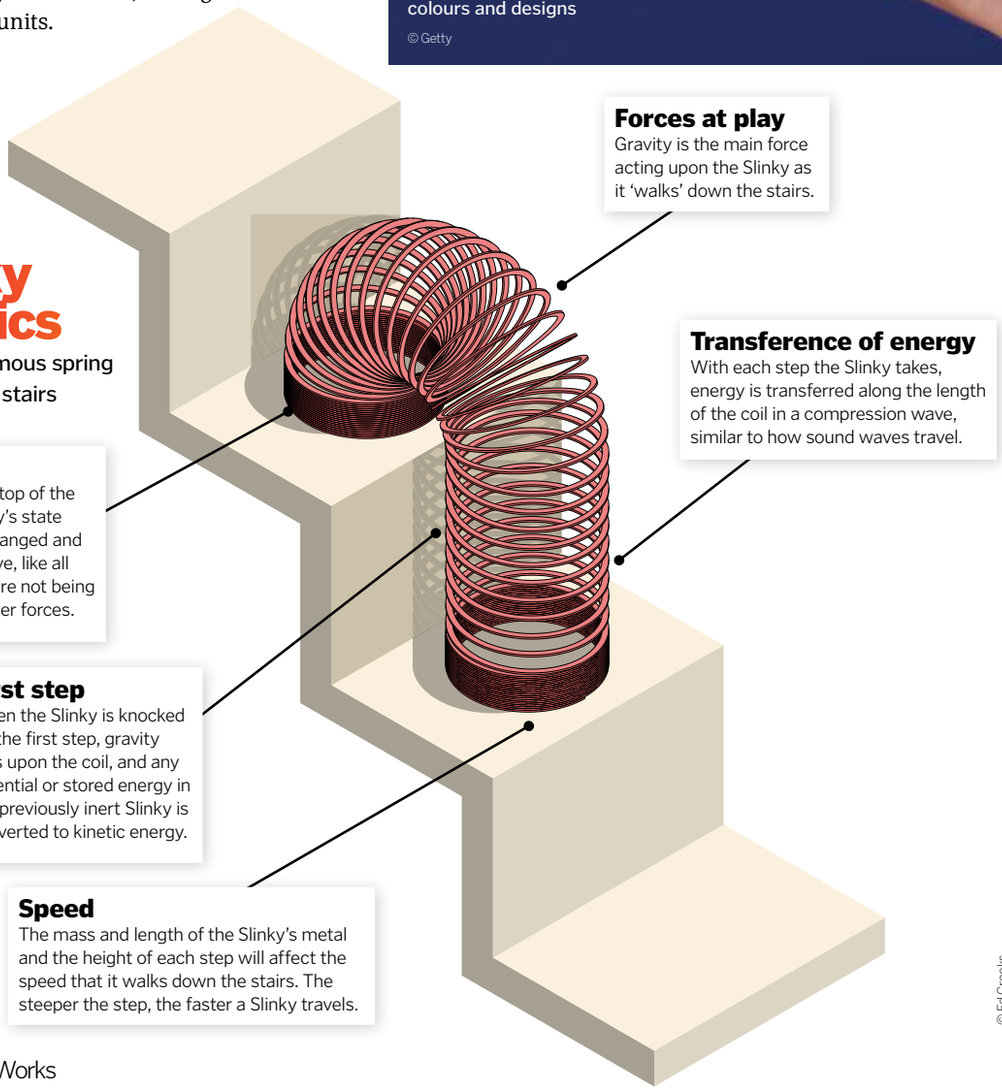
The story goes that the Slinky's inventor, Richard T. James, first discovered the recreational use of the metal spring while working as a naval battleship engineer during the early 1940s. James was developing coils of metal called tension springs that were used on ocean vessels to hold onboard equipment in place. While working at his desk, one of these springs fell and began to 'walk'. Seeing the potential to market the tension spring as a toy, he took the idea home to his wife Betty, who named it the Slinky after looking through a dictionary.

In 1945 James perfected the design of the Slinky, which consisted of approximately 24 metres of wire coiled into a helical five-centimetre-tall spring. The following year, James filed a patent for a machine that could make a Slinky in just ten seconds. The Slinky went on to become the must-have toy of the mid to late 20th century, and in 2000 was inducted into the National Toy Hall of Fame, having sold more than 250 million units.

Slinkies come in lots of bright colours and designs

Slinky physics

How this famous spring walks down stairs



Forces at play
Gravity is the main force acting upon the Slinky as it 'walks' down the stairs.

Transference of energy
With each step the Slinky takes, energy is transferred along the length of the coil in a compression wave, similar to how sound waves travel.

Inertia
Sitting at the top of the stairs, a Slinky's state remains unchanged and it will not move, like all objects that are not being moved by other forces.

First step
When the Slinky is knocked off the first step, gravity acts upon the coil, and any potential or stored energy in the previously inert Slinky is converted to kinetic energy.

Speed
The mass and length of the Slinky's metal and the height of each step will affect the speed that it walks down the stairs. The steeper the step, the faster a Slinky travels.

MR CELLOPHANE

In the kitchen drawers of countless homes around the world, you'll probably find a roll of cling film, or Cellophane. This clear roll of plastic has been around since 1908, when Swiss chemist Jacques E. Brandenberger created a waterproof film intended for coating fabrics.

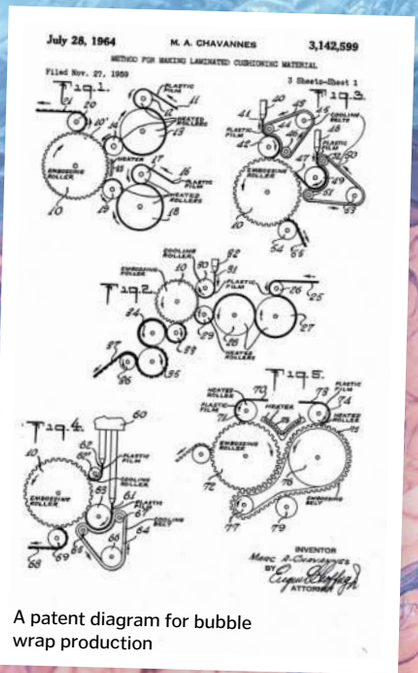
The film appeared after Brandenberger applied a liquid viscose rayon on materials and then peeled away the transparent layer. He saw potential for this new material in the packaging industry, and so patented his creation 'Cellophane', named after the raw material cellulose – the main substance of plant cell walls – and diaphane, an obsolete word meaning transparent.

BUBBLE WRAP WALLPAPER

Bubble wrap is synonymous with sending packages or protecting your precious belongings. However, in the 1950s you were more likely to see it covering your walls than crammed into a box. The idea for bubble wrap came from the minds of Alfred Fielding and Marc Chavannes, who made an attempt to create a textured wallpaper in 1957. Having heated two sheets of plastic shower curtain together, the pair created a single sheet with several trapped air bubbles.

The coinventors obtained several patents for their creation, making attempts to market it as wallpaper and even as greenhouse insulation, but bubble wrap never took off as an interior decoration. The two coinventors founded Sealed Air Corporation in 1960, and the following year diversified their product as a packing material, which soon found success.

The soft bubbles keep what's wrapped inside safely cushioned


July 28, 1964 M. A. CHAVANNES 3,142,599
METHOD FOR MAKING LAMINATED CUSHIONING MATERIAL
Filed Nov. 27, 1959 3 Sheets-Sheet 1

A patent diagram for bubble wrap production

© USPTO

© Getty

Building bubble wrap

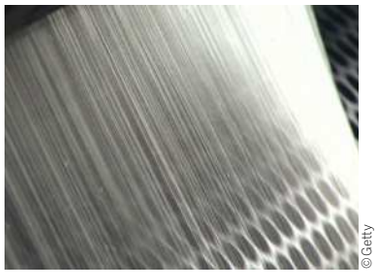
How plastic is transformed from pellets into poppable packaging

© Alamy

© Alamy

1 Plastic pellets
Bubble wrap starts its life as pellets of polyethylene resin. These are vacuumed through pipes to an extruder.

2 Heating up
The resin pellets are heated at temperatures over 260 degrees Celsius. The pellets melt as a result, forming a film.



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3 Sucking up
One layer of film is placed on a cylinder coated with small holes. Using a vacuum, the film is then sucked into the holes.

4 Trapping air
A second layer of plastic film is then rolled on top of the vacuumed film to create a seal, trapping the air bubbles within.

© Getty

5 Cut to size
The now-joined films are rolled into large sheets of bubble wrap and cut into smaller pieces.

PLAY-DOH CLEANER

Around 318 million kilograms of Play-Doh has been squashed between the fingers of children around the world. But did you know that Play-Doh was initially invented as a cleaning tool, rather than a toy? The malleable material was created by Cincinnati-based cleaning company Kutol in the early 1900s. Its intended use was to remove the soot from people's wallpaper, which accumulated from coal-burning fireplaces. However, with the introduction of wipeable vinyl wallpaper and the increase in household oil, gas and electric heating, the need for Kutol's putty quickly declined. Its rebranding was down to the sister-in-law of Kutol's cofounder, who proposed that the putty's non-toxic ingredients meant it would be perfect for playtime.

Play-Doh is completely safe in the hands of children

© Getty

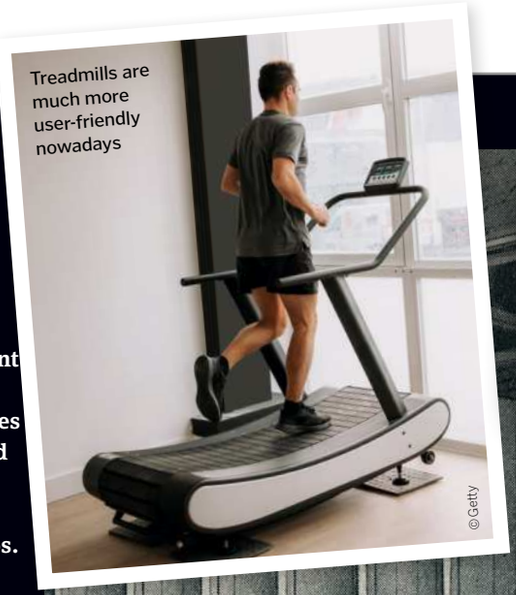
PENAL TREADMILLS

After gorging on a takeaway, hopping onto the treadmill in the morning may feel like atonement for a crime. But that's exactly what treadmills were created for during the early 1800s. Examples of treadmill-like contraptions have been around since the Romans constructed large cranes powered by people walking on a wheel. But the modern-day article was conceived of in the 1800s.

As a cruel method of enforced exercise, the evolution of the treadmill began in 1818, when civil engineer William Cubitt created the treadwheel. It was intended not to improve the fitness of the public, but to punish prisoners.

Installed into Brixton Prison, London, the treadwheel turned under the feet of up to 24 prisoners, each stepping on the wooden slats of an elongated wheel. It included dividers so that prisoners could not socialise, and it could be ten hours before prison guards would let them off the torturous device. Although the invention of the treadwheel was initially designed as a punishment, over time prison officials put them to practical use to pump water or grind corn.

It wasn't until 1902 that the penal treadmills such as Cubitt's creation were abolished in Britain, but treadmill technology continued to evolve for personal fitness.



Treadmills are much more user-friendly nowadays

© Getty

Enforced fitness

How these immoral machines kept prisoners walking for hours

Hold on tight
Handrails were placed along the wheel to prevent prisoners falling off.

Separation
To prevent the prisoners from interacting with one another, penal treadmills were equipped with dividers, similar to bathroom stalls.

Long days
Prisoners spent at least six hours a day on treadwheels as part of their hard labour sentence. This would have equated to climbing around 4,260 metres vertically.

Resistance
In some prisons, guards could alter the resistance of the wheel by opening large panels called vanes. Closing the vanes made it harder to turn the treadmill.

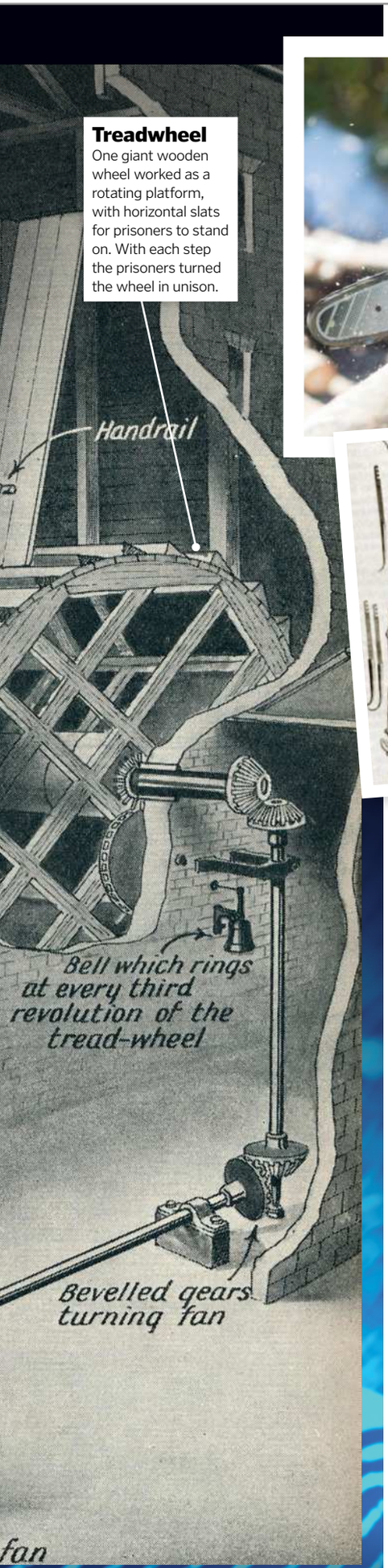
© Alamy

BATTLE-BORN BOTTLE OPENER

Although the exact origin of the corkscrew remains unclear, it's believed that its design was developed from 'gun worms'. These military screws were commonly used in the 1600s to extract trapped musket balls from the barrels of guns. The corkscrew-like devices would twist into the lead of the ball, allowing the soldier to swiftly remove it.

It's believed that this military kit inspired the first generation of simple wine 'cork worms'. It wasn't until 1795 that a British clergyman, Reverend Samuel Henshall, filed the first patent for the corkscrew.

Source: Wiki/Unknown author



Treadwheel
One giant wooden wheel worked as a rotating platform, with horizontal slats for prisoners to stand on. With each step the prisoners turned the wheel in unison.


© Getty


Source: Wiki/Hans555

Chainsaws weren't made with trees in mind

CHAINSAW OPERATIONS

Chainsaws are pretty effective at ripping into wood, but back in the late-18th century, it was bone rather than bark that they tore through. The evolution of the chainsaw began between 1783 and 1785, when two Scottish doctors called John Aitken and James Jeffray invented the chain hand saw. This serrated link chain was used to successfully cut away diseased bone and remove afflicted joints such as the knee or elbow. Over time Aitken and Jeffray's simplistic design was developed, and in 1830 Bernhard Heine created a drive more reminiscent of the modern-day version.

Known as the chain osteotome, Heine's device also used a serrated chain, but included a handle mechanism. It worked in a similar way to hand-powered rotary whisks, but instead of beating eggs, it could precisely cut through bone quickly. The osteotome meant that surgeons could perform surgeries without the restrictions of bone splinters or damaging the surrounding tissue.

The chainsaw's move from bone to bark came about when American inventor Samuel J. Bens patented the first 'endless chainsaw' in 1905. The stationary device consisted of a large, looped, 'endless' secreted chain which was "furnished with driving power, such as a steam-engine, gas-engine or motor of any kind".

WD-40

It's now a household product around the world, but WD-40 was initially created to assist the aerospace industry as a rust-prevention solution. It took WD-40's inventors, a company called Rocket Chemical Company, 40 attempts to perfect this water-displacement formula, hence the name. It was used to coat the skin of the Atlas missile, the US Air Force's first operational intercontinental ballistic missile (ICBM), to prevent it from corroding.

Seeing its potential as a household product and a useful tool for car mechanics, WD-40 hit supermarket shelves in 1958. Although initially perfected in 1953, the same formula for WD-40 is still in use today. Now the iconic blue-and-yellow cans can be found in their millions around the world, and in 2020 the revenue of WD-40 Company reached $408.5 million (£295 million).


WD-40 can hold back rust from rockets

© Alamy

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THE MANY USES OF LISTERINE

© Getty

© Getty

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Other than providing a cool, refreshing oral feeling, Listerine was created to offer an antiseptic solution in the operating theatre. Named after its inventor Sir Joseph Lister, the founder of the practice of antiseptic medicine, the alcohol-based formula was created in 1879 to remove disease-causing organisms and was a good disinfectant for surgical instruments. It was also used as a solution for treating wounds, curing dandruff and cleaning floors. Eventually dentists got hold of Listerine and used it to improve oral hygiene in dental patients. In the 1920s, a marketing campaign that branded Listerine the treatment for the relatively unheard of 'halitosis', or bad breath, made it the go-to mouthwash for the public.

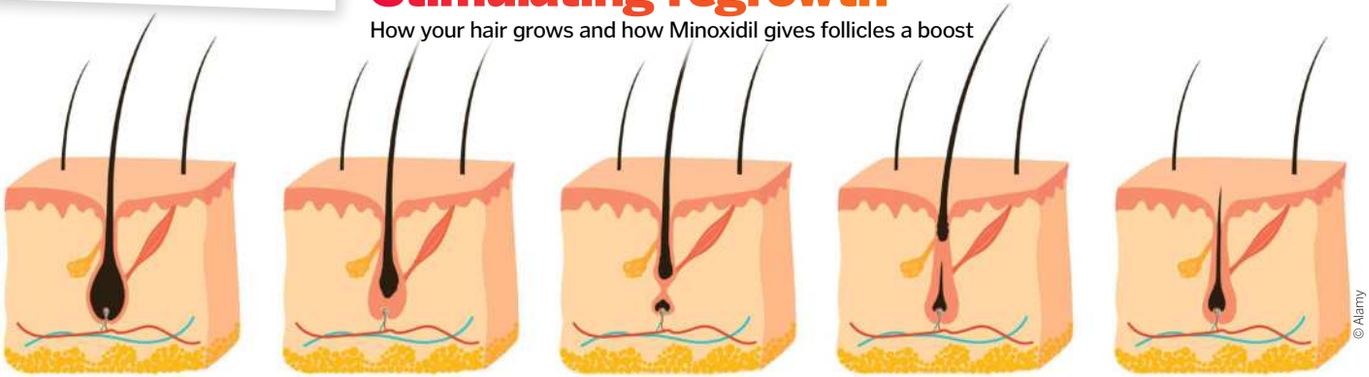
ROGAINE REGROWTH


© Alamy

In the 1960s, pharmaceutical company Upjohn, now part of Pfizer, created a new kind of medicine to treat hypertension (high blood pressure). This medication was called minoxidil and proved popular with clinicians, so much so that the US Food and Drug Administration (FDA) approved it as an emergency protocol for severely ill patients in 1971. It was later discovered that 60 to 80 per cent of hypertensive patients developed an unusual side effect, called hypertrichosis. This condition results in excessive hair growth anywhere on the human body. Researchers quickly found that minoxidil stimulates follicular growth. As a result, in 1988 the new 'Rogaine 2% Minoxidil Solution for Men' was introduced as a prescription-only solution to hereditary hair loss.

Stimulating regrowth

How your hair grows and how Minoxidil gives follicles a boost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Anagen
In the first stage of hair growth, specialised cells divide into cells that make up the shaft of a hair, receiving nutrients from a capillary loop at the base of a follicle.

Catagen
At this stage the hair follicle shrinks, detaches from the capillary loop and moves towards the skin's surface.

Telogen
For around three months a hair will sit in this resting phase before moving on to the exogen phase.

Exogen
In the shedding phase, the hair is discarded from your body. Between 50 and 100 hairs are shed from your body each day.

Rogaine
To tackle hair loss, typically known as androgenic alopecia, minoxidil works to prolong the anagen phase and promotes regrowth via the follicle capillary loop.

CRAVING COCA-COLA

Arguably one of the most beloved carbonated drinks on the market, today Coca-Cola sells more than 1.9 billion servings, enjoyed in 200 countries every single day. The original recipe of the drink, however, would not be so well received these days.

Coca-Cola began as a way for its pharmacist creator John Pemberton to tackle his dependence on morphine. He'd been injured in the Battle of Columbus in the late-19th century, and like many veterans, Pemberton became dependent on pain relief medicines such as morphine. Seeking an alternative to this addictive opiate, Pemberton came across a tonic called French Wine Coca, made by Parisian chemist Angelo Mariani. The tonic promised health rejuvenation from its Bordeaux wine and coca-leaf extract mixture.

The energy-boosting effects of the drink were likely due to the presence of cocaine, the active ingredient in coca-leaf extract. Until 1914 cocaine was not illegal, and was often used in tonics and pills to treat a myriad of medical conditions causing nausea, asthma and constipation.

Pemberton created his version of the wine to sell commercially, but a local prohibition law in 1887 saw quick removal of the tonic because of its alcoholic content. Quickly reformulating the popular beverage, Pemberton substituted the drink's alcohol content, replacing it with sugar syrup and adding caffeine-rich kola-nut extract. The coca-leaf extract remained in the beverage, and the drink became completely cocaine-free in 1929, when scientists removed the psychoactive components of the leaf extract.

© Getty

Coca-Cola's original recipe was a cocaine cocktail

COCA-COLA
SYRUP AND EXTRACT.
For Soda Water and other Carbonated Beverages.

This "Intellectual Beverage" and Temperance Drink contains the valuable Tonic and Nerve Stimulant properties of the Coca plant and Cola (or Kola) nuts, and makes not only a delicious, exhilarating, refreshing and invigorating Beverage, (dispensed from the soda water fountain or in other carbonated beverages), but a valuable Brain Tonic, and a cure for all nervous affections — Sick Head-ache, Neuralgia, Hysteria, Melancholy, &c.

The peculiar flavor of COCA-COLA delights every palate; it is dispensed from the soda fountain in same manner as any of the fruit syrups.

J. S. Pemberton,
Chemist,
Sole Proprietor, Atlanta, Ga.

Source: Wiki/unknown

Inside Coca-Cola

Take a look at what's inside that classic red bottle

Secret ingredients and colour: 0.17307%
A secretive blend of natural flavours are added. Besides coca extract, it's speculated that this includes lots of natural oils, including those from nutmeg, lemon, coriander, cinnamon and orange. Coca-Cola Original uses a colourant called caramel 150d. This additive uses a combination of sulphite and ammonia reactants to create its brownish colour.

Energy boost: 0.00972%
In a standard can of Coca-Cola there is around 34 milligrams of caffeine. However, in the diet version this amount rises to 46 milligrams.

Acidity: 0.1719%
To add tartness, Coca-Cola includes a small amount of phosphoric acid. However, this acid wreaks havoc on the enamel of your teeth.

Sweet taste: 10.8%
In around half a litre of Coca-Cola there is approximately 65 grams of sugar.

Fizz: ~89%
Around 90 per cent of Coca-Cola is water, which has been pumped with purified carbon dioxide to give it its fizz.

THE MOOD BOOSTER

Similar to the creation of Coca-Cola, the refreshing taste of 7UP was concocted as a life-changing elixir. In 1929, Charles Leiper Grigg created a new lemon-flavoured drink called 'Bib-Label Lithiated Lemon-Lime soda'. The formula for the drink contained lithium, which continues to be used as a mood enhancer to treat conditions such as depression and bipolar disorder. 7UP hit supermarket shelves only two weeks after the American stock market crash in 1929 and the start of the Great Depression. Lithium was removed from 7UP's recipe in 1948 following a government ban in America of its use in soft drinks.

Old branding for 7UP marketing it for the whole family

© Alamy

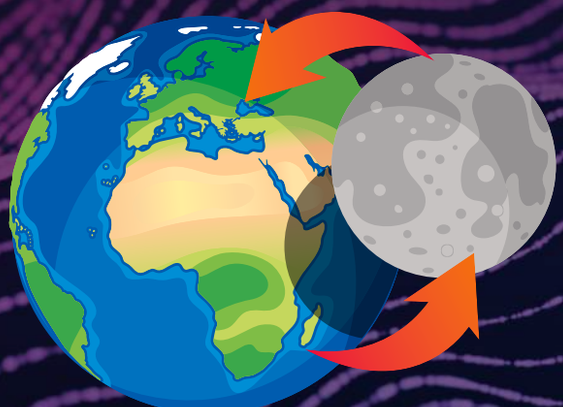
INVENTIONS BY NUMBERS

3.1%

A significant fraction of all beverages consumed around the world are Coca-Cola products

3,500 BEVERAGES

If you were to drink a different Coca-Cola product every day, it would take you over nine years



If every drop of Coca-Cola ever made was bottled and stacked, the tower would reach the Moon and back over 2,000 times

97%

Listerine claims its mouthwash can kill nearly all germs in your mouth

There are more than 50 colours of Play-Doh

90%

In 2005, fingerprints pressed into Play-Doh could fool the majority of fingerprint scanners

30
The record number of steps a Slinky has descended

30 METRES
When fully extended, the largest Slinky on Earth is as tall as a nine-storey building

The initial run of 400 Slinkies sold out in just 90 minutes

UP TO 14,000
The average number of rotations a chainsaw chain makes per minute

6.98 METRES LONG 1.83 METRES HIGH
'Big Gus' is the largest working chainsaw in the world

39 LAYERS
One estimate says that it would take several dozen sheets of bubble wrap for you to survive a six-storey fall

2,681
The record for the most people popping bubble wrap simultaneously

1952
It wasn't until the mid-20th century that the first motorised treadmill was invented

13 HRS 42 MINS 33 SECS
The record speed for running 100 miles on a treadmill

ANATOMY OF A ROCK CONCERT

Explore the advanced sound technology and special effects that keep live music audiences wanting more

Words by **Ailsa Harvey**

No recording can replace the experience of standing before your favourite band, surrounded by many thousands of like-minded fans as you shout back the lyrics in time with the performers. For many, the unique sound of a live gig helps them to connect with their idols. With less autotune and editing to hide behind, the authenticity of the raw music is often more appreciated. The songs will sound slightly different to the recordings you know inside out, as an irreplicable and unique version is created for those inside the venue.

You might have come to the event to see the band members, but there are many more elements required to build a rock concert. The stage before you isn't just an elevated platform for music to be performed on. It's also a carefully calculated piece of art, designed to encapsulate the crowd and complement the sound in new and exciting ways. Before the crowd arrives at a festival or event, the stage's technology is installed and tested. Many weeks before the event, the production manager works with lighting technicians to choreograph and manufacture lighting and visuals. The production manager relays to the technicians the colours and effects needed for the set, and it's the job of the lighting technician to carry out these transitions behind the scenes. This might involve keeping lights flashing in time with the melody, explosions of smoke or fire at the climax of a song or changing the colour schemes of lighting between songs.

The evolving technology that musicians use on stage enhances their performance and makes them more memorable for the audience. Even though the sound is being played live, bands have experimented with bringing the recording studio on stage in the form of loop pedals. By recording sections of vocals or instruments to be played continuously on a loop, they can layer their baselines and melodies to add more depth to their performance without having to increase the number of musicians.

© Getty

A band's equipment

What instruments can you expect to see on stage?

© Shutterstock

Drums
The role of the drummer is to set the rhythm. Drums and cymbals are hit with drumsticks and a foot pedal to set the beat. Aside from keeping time, the drummer can add creative improvisation and melodic variation.

Microphone
Held by the singer or attached to a stand, the microphone amplifies the vocals of any performer. This is vital to balance the volume of quiet vocals with louder instruments.

Bass guitar
A bass guitar plays about an octave lower than a standard guitar. The bassist acts as a link between the rhythmic and melodic components of the band.

Amplifier
For electric instruments, amplifiers convert the electric signals produced into a high-power replica. The loud sound produced is played to the arena through concert speakers.

Lead guitar
The lead guitar is usually an electric one. This is used to play the melodies of a song and is often used for guitar solos.

A virtual experience

As immersive technologies improve their power to make virtual and augmented reality more believable, music concerts are becoming more diverse. Virtual-reality headsets are giving more fans the opportunity to buy 'front row' seats and the illusion of standing before a live performance without needing to leave the house. For those who are put off by standing around for hours or are uncomfortable in large crowds, this provides the opportunity to watch and listen in comfort and in their own space.

On other occasions, it might be the performer who is virtually at the venue. Hologram concerts are on the rise, allowing iconic deceased performers to appear to take to the stage once more. Using recordings of old performances, this allows their biggest fans to remember what it was like to experience them live, or attend one of their concerts if they were never able to. Technically these are not true holograms, however. A true hologram is a freestanding, three-dimensional structure which doesn't require a material to be projected onto. In these concerts the 'holograms' are light reflected onto a 2D glass pane, but are often still referred to as holograms as they create a similar effect.

© Getty

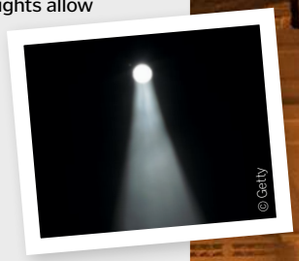
A hologram of deceased musician Roy Orbison played a concert in Madrid in February 2021

WELCOME TO THE STAGE

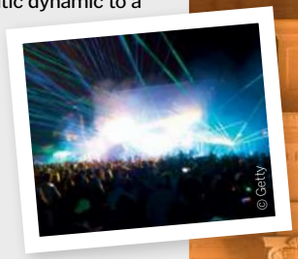
Take a tour of some of the technology enhancing live gigs

5 WAYS TO LIGHT THE SHOW

1 Spotlights
These focus strong light directly onto a performer. Often manually controlled, spotlights allow performers to remain visible to the audience and also work to add contrast when other lights are dimmed.


© Getty

2 Lasers and strobes
Flashing strobe lights and the flickering narrow beams of lasers can add a dramatic dynamic to a rock concert stage. Fog machines provide particles to scatter the light in, making the razor-sharp light visible.


© Getty

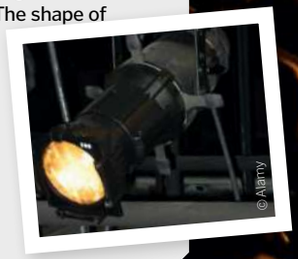
3 LEDs
These are popular, cheap lights that can project a range of colours onto a stage. They are also relatively energy-efficient, using less power and producing less heat than other lighting options.


© Getty

4 Floodlights
These lights are similar to spotlights but cover a larger area. When they illuminate the entire stage, it's called a wash.


© Getty

5 Ellipsoidal reflector spotlight (ERS)
The ERS is a spotlight with added special effects. The shape of the light can be changed and unlimited light patterns can be added to its projection.


© Alamy

© Getty

Haze
Haze machines vaporise water and glycerin-based fluids. As this vapour escapes the machine, it hits the cold air and condenses to form fog.

Motion graphic technology
The entire back wall of a stage is often a large digital screen. In some cases, a transfixing animation will move in time to the music, connecting the crowd's visual senses with the sound.

Pyrotechnic chemistry
Violent yet controlled fiery explosions are bound to turn any rock concert into an elaborate spectacle. Small amounts of a flammable material, such as powdered aluminium, are brought into contact with fuel and an oxidiser, such as nitrate, in a cigarette-sized tube to form this reaction.

Crowd syncing
The crowd can also be utilised for lighting effects. Many events involve wearing a wristband for access. These may have lights inside that can be programmed to flash in sync with the music.


Fog machines are primarily used to create a visual effect, while haze machines help lights and lasers be seen better

© Getty

Truss
Made of metal triangles to distribute the weight, these structures are designed for lights and other equipment to be attached to. Sometimes the entire stage is constructed of trusses.

Sound system
The crowd has come to hear a band perform their music, and so sound quality is vital. The size and output of the speakers will vary based on the location.

Inside an ERS light

The popular ellipsoidal reflector spotlight is incredibly versatile

Light source
Screwed into the back compartment is a lamp. This bright light has four filaments to increase efficiency.

Attachment area
This handle is where the ERS attaches to the top or side of the stage. Once secured, the angle can be adjusted.

Shutter closure
Adjusting the shutters – by pulling them in or out – alters the size of the gap that the light can shine through, and therefore the light's width.

Focus adjustment
Depending on whether the concert requires defined light or a subtle, atmospheric hue, turning this bolt can make the light softer or sharper.

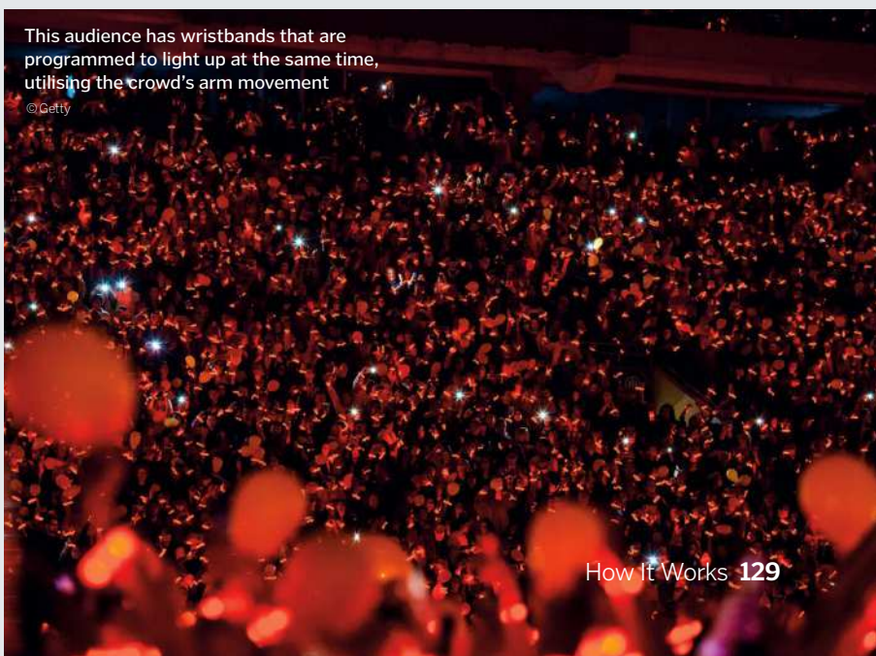
Shadow effects
Templates with a variety of patterns slide into this section. When the light shines through them from the back of the device towards the lenses at the front, the template creates shadows that project patterns onto the stage.

Adding colour
At the front of the light, a coloured gel can be placed into a slot. These are quick and easy to slide in and replace.

AR ZONE! SCAN HERE

Illustration by © Adrian Mann

Crowd control
Infrared cameras and other sensors can detect the most populated areas of a crowd so security can intervene before danger arises. Wearable tech such as radio-frequency identification tags in wristbands can convey data of a crowd's movements.



This audience has wristbands that are programmed to light up at the same time, utilising the crowd's arm movement
© Getty

What's inside a fridge?

How a cycle of evaporation and condensation keeps food cold

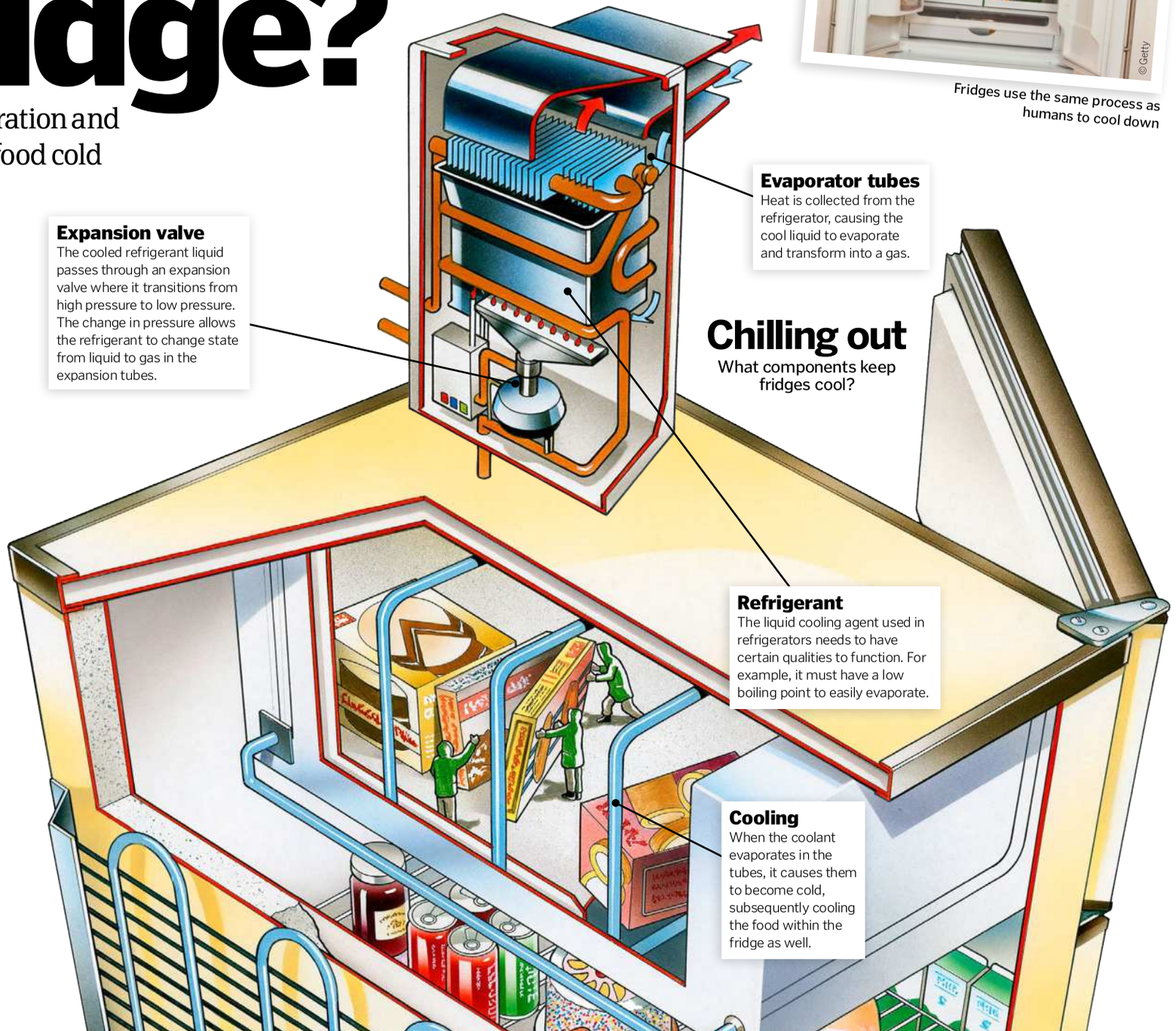
Words by **Scott Dutfield**

Fridges use the same process as humans to cool down

Keeping some foods cool is paramount in delaying the growth of harmful bacteria. Temperatures above four degrees Celsius are the optimal conditions for many bacteria and fungi to grow and spoil food. If food is stored below that temperature, its longevity can be increased.

Across thousands of years, humankind has developed different methods of refrigeration to battle bacteria and store food safely. The ancient Greeks dug snow pits to store food, and during the 18th century Europeans used salted ice as a natural freezer. However, it wasn't until the early 1800s that refrigerators similar in design to today's kitchen essentials were developed.

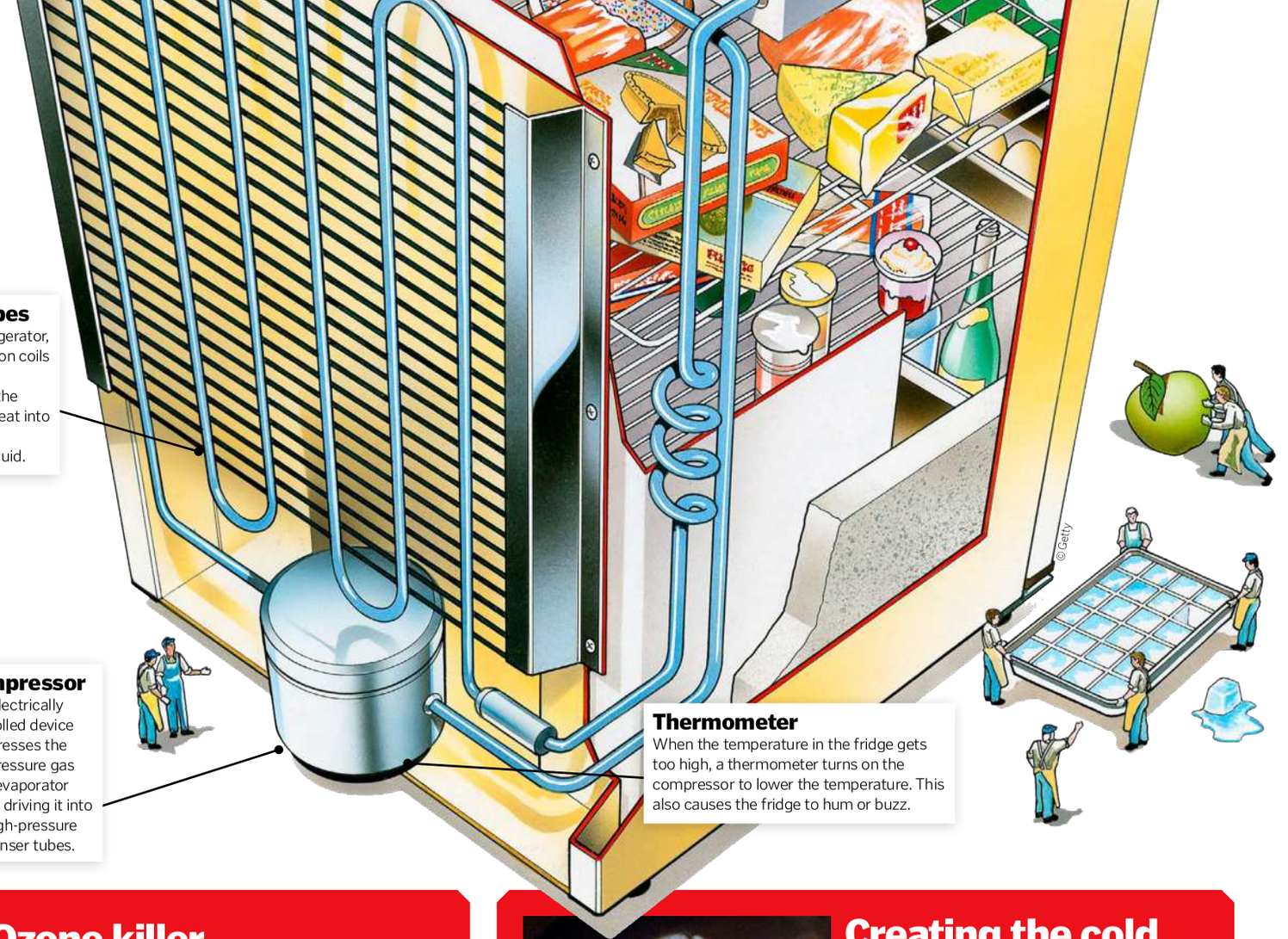
Modern-day refrigerators rely on a process called evaporative cooling to function. Evaporative cooling depends on the change of a liquid's molecular state into a gas via evaporation. This process can remove heat from a surface and lower the surrounding temperature. In human biology, this is the natural cooling process of sweating. Once sweat has formed on the skin, body heat



evaporates the liquid into a vapour, taking the heat from the skin with it and leaving a cooling sensation behind. Similarly, applying rubbing alcohol to the skin results in a quick chill because the low boiling point of alcohol makes it evaporate faster.

In place of skin, refrigerators have an internal network of pipes that run a liquid coolant called a refrigerant. The refrigerant is heated and evaporates, then the vapour is funnelled to external coils at the back of the machine where the heat is released, leaving the internal pipes nice and cool.

Evaporative cooling is the predominant method used in refrigerators, though researchers are developing innovative ways to keep our food cool, including the investigation of molecules called neopentyl glycol crystals as an alternative. When these crystals are held under pressure using magnets, they become cold very quickly.

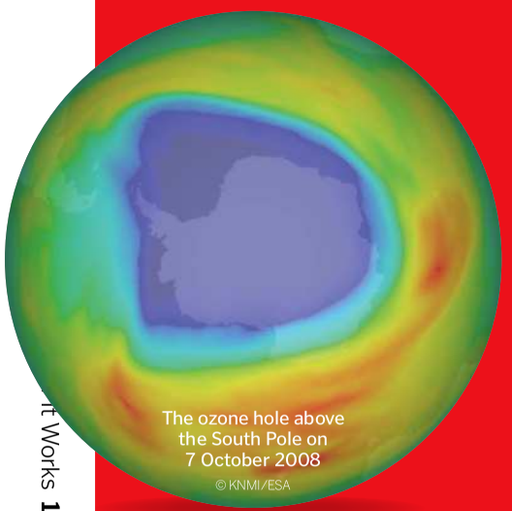


Condenser tubes
At the rear of the refrigerator, a series of condensation coils facilitate the hot gas collected from inside the fridge to release the heat into the ambient air and condense back into liquid.

Compressor
This electrically controlled device compresses the low-pressure gas from evaporator tubes, driving it into the high-pressure condenser tubes.

Thermometer
When the temperature in the fridge gets too high, a thermometer turns on the compressor to lower the temperature. This also causes the fridge to hum or buzz.

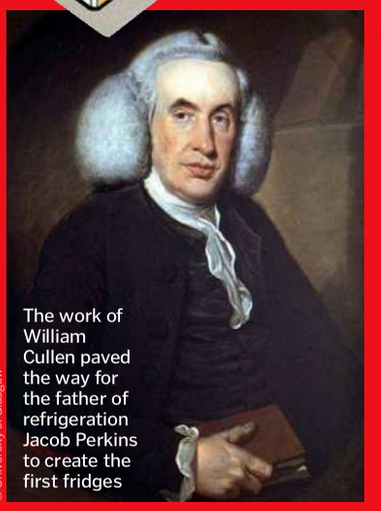
© Getty



The ozone hole above the South Pole on 7 October 2008
© KNMI/ESA

Ozone killer

In the 1920s, early versions of the modern-day fridge used refrigerants called chlorofluorocarbons (CFCs). These compounds offered a safer alternative to the flammable and toxic chemicals that had been previously used. Although safer in terms of preserving human health, their environmental impacts were catastrophic. Upon release from damaged or discarded refrigerators, CFCs have a nasty tendency to react with oxygen molecules in the ozone and cause holes in it. The ozone is crucial in protecting life on Earth from deadly ultraviolet radiation from the Sun. Having discovered the environmental cost of using CFCs, from 1974 large parts of the world began banning their use. Currently 197 countries hold the ban. Refrigerator engineers turned to a less damaging compound called hydrofluorocarbons (HFCs), which remain in common use in fridge production.



The work of William Cullen paved the way for the father of refrigeration Jacob Perkins to create the first fridges
© University of Glasgow

Creating the cold

The modern-day refrigerator resulted from the collaborative effort of scientific minds over many years, starting with Scottish inventor William Cullen. In 1748, Cullen demonstrated the basis for the first artificial method of refrigeration at the University of Glasgow. Cullen used a pump, vacuum and a volatile compound called diethyl ether, which when heated evaporated, creating a cooling effect on the apparatus. Later, in 1835, American inventor Jacob Perkins invented the first refrigerator to use a vapour compression cycle. It was informed by Cullen's work with the design assistance of another inventor, Oliver Evans. This system used compressed vapours from liquid ammonia as the refrigerant.

FLOATING RESEARCH LABORATORIES

Words by **Mark Smith**

THESE GROUNDBREAKING OCEAN-GOING VESSELS WERE DESIGNED TO UNCOVER THE MYSTERIES OF THE DEEP

The seafaring City of Meriens was designed around one of the ocean's most recognisable creatures: the manta ray

Looking like something from a sci-fi movie, the SeaOrbiter was designed to tower above the waves as it made its way through some of the most unexplored parts of the world's oceans. Featuring its own underwater platform, sophisticated science labs and a sub-ocean 'garage' for submarines and divers, the breathtaking vessel has been described as the 'Starship Enterprise of the sea'. Work was due to begin on the ship in 2014, and it was designed to host a crew of up to 22 for long-term scientific missions lasting over six months. It was intended to roam the oceans and deploy submersible vessels at depths of up to 3.7 miles.

Its scale when seen on the horizon would have been immense. While modern ships usually sit flat to the surface and have most of their mass laid out horizontally, SeaOrbiter was to resemble a floating tower, casting an imposing figure on the horizon like a much larger version of the galleons of old. It would rise to a total height of 51 metres – the height of Nelson's Column in London – with over half submerged below the ocean.

Designed not just to roam the seas, but also to explore their depths, six of the SeaOrbiter's 12 decks were to sit below sea level, bringing the undersea realm to life and perfect for providing uninterrupted underwater observation for the scientists and explorers aboard. Its goal was simple – to pull back the curtain on one of nature's most unexplored habitats.

Despite covering 70 per cent of our planet, but with only five per cent explored and less than 20 per cent mapped, our oceans are still largely a mystery. What's more humans have explored less than one per cent of the deep ocean. In fact, we know less about the ocean floor than we do about the surfaces of the Moon and Mars. In addition to scientific study, it was to function as a global educational and communications platform, enabling scientists on board to share their findings with fellow experts and the public alike, right around the planet, as well as raise awareness of environmental issues.

The brainchild of French architect Jacques Rougerie ,who took his inspiration from Jules Verne, Jacques Piccard and Jacques-Yves Cousteau, work on the $50 (£35) million project has since stalled. Construction of the 1,000-tonne vessel had been due to start in 2014, but by May 2015 only the Eye of SeaOrbiter, the first part of the construction of the vessel, was successfully completed. Construction was made possible by a crowdfunding campaign.

City of Meriens

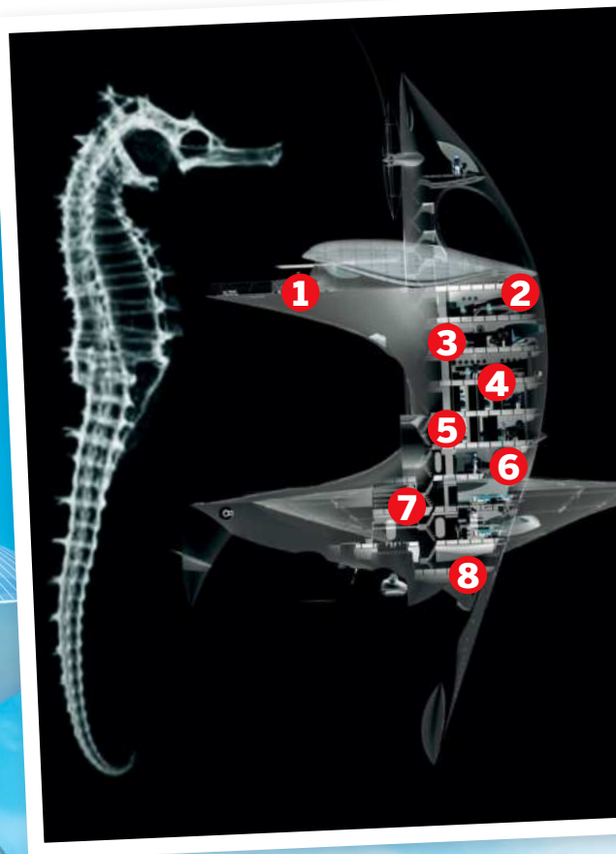
SeaOrbiter isn't the only groundbreaking design from the mind of Jacques Rougerie. The City of Meriens is designed to be nothing less than a floating city, measuring a gigantic 900 metres by 500 metres and housing up to 7,000 scientists and students from around the world.

Designed in the image of a giant manta ray, it will come equipped with labs, classrooms, lecture theatres, living quarters and areas for leisure activities and sports, making it a long-term place to live and work in order to facilitate research projects.

The design was picked for its ability to withstand harsh sea conditions, with most of its mass being below the water to help keep it steady. At its centre will be a large 'lagoon', where vessels such as the SeaOrbiter could dock. There are no plans to build the city yet, but if it ever takes to sea it would mark a new era in ocean research.

SeaOrbiter design

The design of this vessel is inspired by the seahorse



1 Boat storage
Smaller research craft are kept here when not being used.

2 Upper deck
This area is where the engine rooms and storage facilities are located.

4 Command bridge
The central hub of the vessel is where all ship operations are controlled.

6 Sleeping area
The captain's room and bunk areas for the rest of the crew are located here.

3 Diving room
This section is a scientific wet lab and diving room.

5 Multidisciplinary lab
This modular area is where you will find the medical zone and fitness area.

7 Communications area
This section is below the waves and contains communications and sanitation areas.

8 Underwater research area
Pressurised living quarters, an underwater garage and a diving zone make this the hub of underwater operations.

French designer Jacques Rougerie with a model of his SeaOrbiter vessel

© Getty

© Jacques Rougerie

Anatomy of Proteus

The proposed underwater research lab is equipped for life beneath the waves

Unique design
Proteus will have a spiral design spanning 370 square metres.

ISS of the sea
Proteus is designed to follow a modular layout like the International Space Station (ISS).

Support craft
Underwater vessels will be able to dock with the lab for supply runs and to transport crew.

Pod design
The pods around the sides will contain crew quarters, labs and medical bays.

Underwater working
Divers will be able to stay underwater for days and weeks at a time, as they will not have to acclimatise before returning to the surface.

Stilts for stability
The stilts will ground the base to the seafloor so it can withstand ocean currents.

Work on a smaller scale was also carried out. The Norwegian Marine Technology Research Institute MARINTEK conducted tank tests with a 1:15 scale model. Advanced theoretical studies and hydrodynamic tests were carried out to improve SeaOrbiter's seakeeping performance and to optimise its behaviour in waves and wind. But despite what appeared from the outside to be steady progress, as of today there is still no sign of any further work being carried out. While mystery may surround the apparent lack of further progress on the vessel, projects to uncover the secrets of our oceans have continued apace.

One such development is the Proteus project. Designed to be an underwater lab, the goal of its developers is for it to become an underwater version of the International Space Station (ISS). The undersea laboratory will be a 370-square-metre structure that can be a home for up to 12 people at a time – but that could just be the start. Like the ISS, Proteus is designed to be modular in nature, so more pieces could be added as time goes by, making it even bigger.

Proteus will feature a two-storey circular structure fastened to the ocean floor on stilts, with protruding pods that house labs, living quarters, medical bays and a 'moon pool' – a hatch where divers can access the ocean floor. When constructed, it will sit on the seafloor about 18 metres below the surface off the island of Curaçao in the Caribbean Ocean. Once in place, it will allow scientists to dive and work for longer without having to return to the surface.

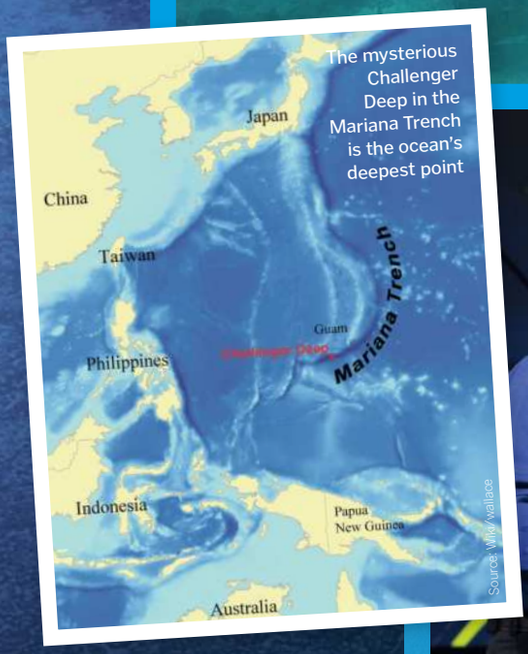
Power for the station is expected to come from solar energy and the movement of the ocean. It may also have what is thought to be the first underwater greenhouse in the world, enabling the lab's crew to grow some of their own food.

In some ways, working beneath the ocean is every bit as challenging as working in space. Diving takes a toll on the human body because when it is underwater, pressure causes nitrogen in the lungs to dissolve into the body. The longer a diver is underwater, the greater the build-up of nitrogen.

If a diver comes back to the surface too quickly, the nitrogen can form bubbles in their blood, which can make them extremely ill and confused, known as 'the bends'. To stop it happening, divers have to slowly come back to the surface while they gradually

The Aquarius Reef Base is an underwater facility off the coast of Florida

Source: NASA



The mysterious Challenger Deep in the Mariana Trench is the ocean's deepest point

Fabien Cousteau, grandson of Jacques Cousteau and the man behind Proteus

© Getty

acclimatise. The process can take hours, meaning all of that potential research time is lost. This is what makes an underwater research hub so potentially groundbreaking. If divers were able to stay underwater for long periods of time on a facility like Proteus, they could undertake dives night and day. This would have huge benefits for their ability to explore the deep.

The man behind the Proteus project, conservationist, aquanaut and filmmaker Fabien Cousteau, is the grandson of legendary ocean explorer Jacques Cousteau, one of the famous 'musketeers of the sea', who was also an inspiration to the architects of the SeaOrbiter.

The structure itself was designed by industrial designer Yves Béhar. Together they hope to raise the $135 (£95) million needed to turn their dream into reality. If successful, it will be operational by 2023. Cousteau says that once it is up and running, as well as studying the ocean it will also allow scientists to research new ways of growing food, creating energy and even carrying out medical research.

If it is a success, Cousteau says there could one day be a whole network of underwater habitats in different oceans around the world. They would be able to warn of tsunamis and hurricanes, and also allow for pioneering research into things like robotics, sustainability and energy. While it may be trailblazing in both scope and ambition, Proteus will not be the first underwater lab. Another facility called Aquarius has been operational since 1986.

Positioned off the coast of Florida, Cousteau previously set a record for living underwater when he worked there for 31 days in 2014. The 37-square-metre base can only accommodate six people, while the Proteus lab will be ten times bigger at 370 square metres, and can house double that number.

Q&A

SeaOrbiter designer Jacques Rougerie is a French architect and oceanographer who specialises in underwater habitats. How it Works speaks to him about SeaOrbiter's future and his thoughts on the future of ocean exploration

What is happening with SeaOrbiter at the moment? Has the project stalled?
The SeaOrbiter project is in no way stopped, especially since it is increasingly anchored in major current issues on climate and ocean biodiversity. It is more relevant than ever. However, the international situation due to the coronavirus has slowed down the search for funding. But more than ever we are determined to carry out this project on an international level.

Where did you get design inspiration for SeaOrbiter?
SeaOrbiter is the synthesis of 30 years' of experiences related to the realisation and the experimentation of underwater habitats that we have carried out, such as the underwater houses Galathée, Hippocampe or Aquabulle, or the semi-submersible vessels with transparent hulls like Aquascope and Aquaspace that we have also made.

Given the specificity of the SeaOrbiter program to maintain crews for long periods of time under the drifting sea, we started with a concept of biomimetic architecture: this vessel is vertical, like a hippocampus [part of the brain associated with learning and memory].

How does SeaOrbiter compare to your other ocean projects? Which is your favourite?
The different submarines or underwater research boats around the world are not able to do what SeaOrbiter does: an international base that allows a crew to constantly observe and listen under the sea and which is able to exit directly underwater at any time.

What do you think of other sea projects currently being undertaken, such as the Proteus underwater lab?
I happen to work as an architect in collaboration with Fabien Cousteau on Proteus, which is a magnificent project for an international fixed submarine station. It is a research base with versatile programs to develop a [ocean-friendly] Blue Society on the scale of *The Blue Planet*.

Workers in China on the production line of silicon wafers

How microchips are made

Robert Noyce was one of the brains behind the modern microchip

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These tiny, silicon devices power the modern world

From the mobile phone in your pocket to the computers that make spaceflight possible, virtually no piece of modern electronic equipment would function without the humble microchip. Also called a chip, a computer chip, an integrated circuit or IC, a microchip is just a set of electronic circuits on a small, flat piece of silicon.

Sitting on top of the chip are components called transistors, which act like tiny electrical switches that can turn a current on or off. You can fit a huge amount of transistors on a chip, with one the size of a fingernail containing billions of them. The chips themselves are made from silicon, which is in turn made from a type of sand called silica. The sand, which is made from silicon dioxide, is melted down and cast to form a big cylinder known as an ingot, which is then sliced up.

A layer of silicon dioxide is grown on the surface, which is covered with a photosensitive chemical and exposed to ultraviolet light that's shone through a patterned plate, or 'mask', that kind of acts like a stencil. This hardens the areas exposed to the light. These hardened bits then get stripped away, leaving a three-dimensional landscape on the chip that looks just like the original circuit design on the mask. Wiring and transistor components are then built onto it.

There are two main types of microchip: memory chips store information, while logic chips function as the brains of electronic devices. In 2019 more than 634 billion chips were manufactured around the world as part of an industry worth £410 billion ($567 billion) a year.

But the last year or so has seen a shortage of chips, as manufacturing slowed during the coronavirus pandemic. Changing consumer habits mean there's also been a spike in demand for electronic devices.

History of the microchip

The first microchip was produced in 1974, and two men are credited with having the original idea. In 1958, engineer Jack Kilby had recently joined a company called Texas Instruments. Because he hadn't accrued as much holiday time as his colleagues, he found himself alone in the lab with time on his hands. It was then that he conjured up the idea for what would become the microchip. But over in California, another man had similar ideas. In January of 1959, Robert Noyce was working at the small Fairchild Semiconductor start-up company, where he conceived the idea for a whole circuit which could be made on a single chip. In 1961 the patent office awarded the first patent for an integrated circuit to Robert Noyce while Kilby's application was still being analysed. But both men are now acknowledged as having independently conceived the original idea.

© Getty

Nobel Prize winner for physics Jack Kilby at the Swedish Academy in Stockholm in 2000

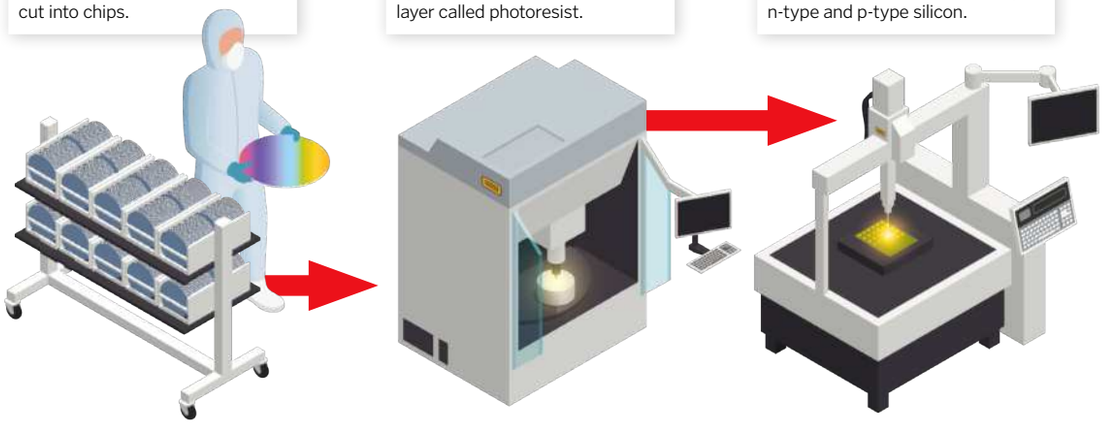
Forging a microchip

The industrial process that produces the integrated circuit is well-established

1 Making wafers
Silicon crystals are grown into long cylinders, which are sliced into 'wafers'. These can then be cut into chips.

2 Masking
Wafers are heated to coat them in silicon dioxide. Ultraviolet light is then used to add a hard layer called photoresist.

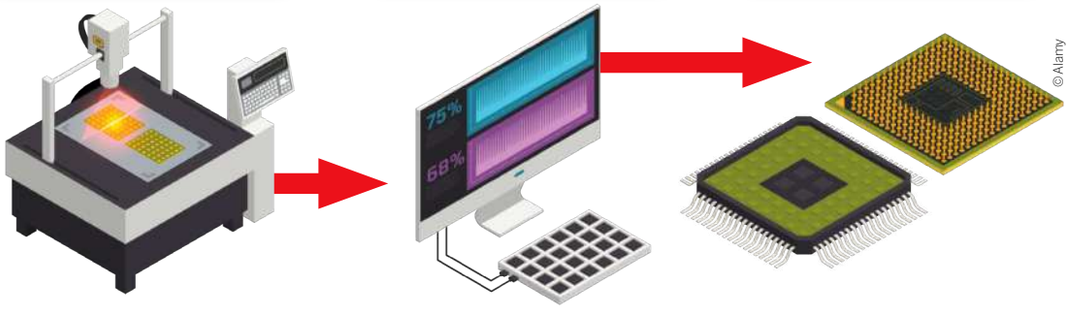
3 Etching
A chemical is used to remove the photoresist, making a template pattern which shows where to put n-type and p-type silicon.



4 Doping
The etched wafers are heated with gases to make areas of n-type and p-type silicon. More masking and etching may follow.

5 Testing
Long metal connection leads run from a testing machine to the terminals on each chip. Any chips that don't work are rejected.

6 Packaging
The working chips are cut out of the wafer and packaged into protective plastic, ready to be used.



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5 FACTS ABOUT MICROCHIP TECHNOLOGY

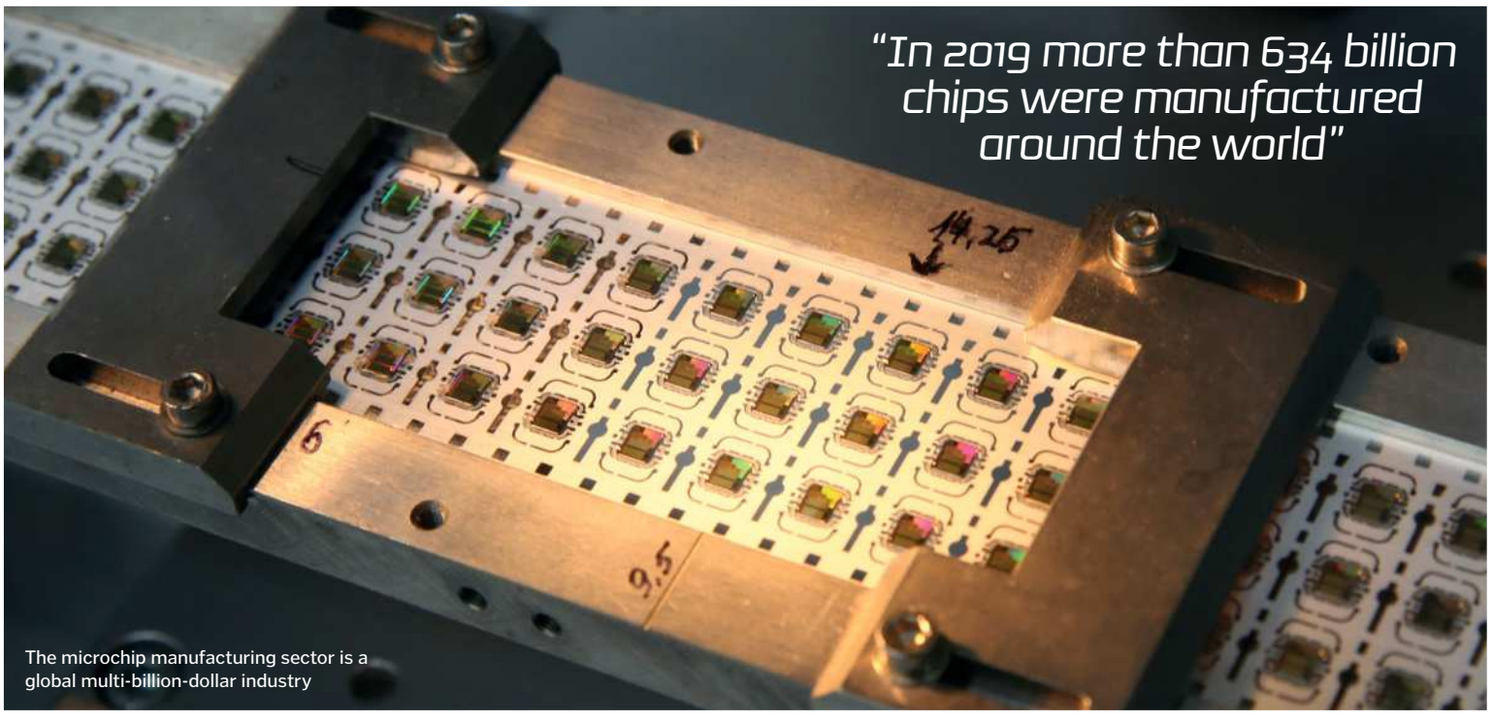
1 Smaller and smaller
When integrated circuits were created you could only fit one transistor, three resistors and a compactor on one the size of your middle finger; now you can fit 125 million transistors.

2 Calculating success
Jack Kilby is also well known as the inventor of the portable calculator, which he created in 1967. In 1970 he was awarded the National Medal of Science.

3 Famous founder
As well as having the idea for the microchip, in 1968 Robert Noyce also founded Intel, the company responsible for the invention of the microprocessor.

4 Abundant substance
The building block of chips, silicon, is one of the most common substances on the planet. It is found in minerals that make up 90 per cent of Earth's crust.

5 The world's purest
The purest silicon is found in quartz rock, and the purest quartz in the world comes from a quarry near Spruce Pine in North Carolina.



The microchip manufacturing sector is a global multi-billion-dollar industry

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HOW ARE HOUSES BUILT?

FROM PLOT-PICKING PROTOCOLS TO FINALISING UNIQUE DESIGNS, FOLLOW THE PROCESSES THAT BUILD OUR HOMES

Words by **Ailsa Harvey**

The oldest known civilisations first cropped up over 5,000 years ago. As these communities began settling in one area, they gathered the materials around them to create long-lasting shelters. Millennia have passed, and today we use a growing abundance of materials, including bricks and cement, to build the best possible homes that stand the test of time. But what processes are used today to place a roof over our heads?

You can no longer gather the materials and build a house wherever you please. Before you can start any work that includes building new houses, making significant changes to your home or changing the primary use of a building, planning permission needs to be obtained. This prevents houses appearing without notice where they could invade the privacy of other home owners, drastically increase traffic or reduce habitats in protected areas. Requests are sent to local councils, often with the help of architects and planning consultants.

When building eventually commences, workers on construction sites analyse small details carefully. From the area of a plot to the measurements of a house's frame, greater accuracy improves building times and makes the environment safer for construction and living. Each person on site has been trained in specific roles, and as a team their specialised skills combine to produce the highest quality buildings. Each successful build is not merely another structure added to the landscape, but a personal space for someone to call home. Around 90 per cent of our time is now spent inside, and 70 per cent of this takes place within the walls of our own homes. Being used as areas to both work and wind down, we need houses to be built to the highest standards to keep us safe and comfortable every day.


A frame is built first to create the roof's shape

© Alamy

"Each person on site has been trained in specific roles"

Construction through the centuries

Ancient houses were built using more perishable materials than the sturdy stuff we use today. The ancient Egyptians, for example, began making flat-roofed homes with wood and Sun-dried clay bricks in 3100 BCE. Around 600 years later, people discovered that baking the bricks in fire made the clay stronger, while adding a silicate glaze made them more resistant to storms.

During the Middle Ages, in the 15th century, houses in Europe were built with stone or brick foundations. Whole tree trunks were used as corner posts and wooden beams joined them together to create support. The walls were typically filled with a clay mixture and straw, and most Tudor houses had a thatched roof. These consisted of layers of dry vegetation, such as straw and wheat, which drew water away from the layers beneath.

In the 1800s, during the Industrial Revolution, bricks began to be mass produced in factories instead of being made by hand. Brick became more affordable as a building material, and other strong materials, such as steel frames, became widespread.

There are still more than 60,000 thatched roofs in the UK today

© Getty

IMPORTANT ROLES

Many different people with specialised skills work together to construct a home

© Getty

Builder

Physically assembling the house mainly comes down to the builders. They also measure materials and carry out precise checks to keep brickwork and other structures straight and consistent.

© Getty

Architect

The unique design of each house is formulated by a qualified architect. Architects help create a look that their client desires, while also keeping plans safe and functional.

© Getty

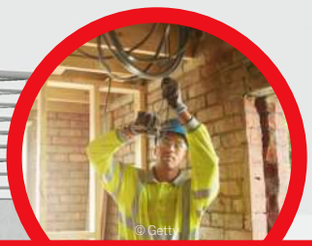
Civil engineer

Site engineers oversee construction and advise plans based on their knowledge of mechanical function. This will include moderating drainage systems, driveway functionality and utility positioning.

© Getty

Plumber

Plumbers make sure heating and water systems are in place and functioning correctly to all appliances. They can also add waterproofing to the walls and roof of a home.



© Getty

Electrician

Making electrical installations during building is essential, ensuring that electricity can reach all rooms. Electricians also carry out risk assessments when wiring.

© Getty

Interior construction

When the main body of the house is completed, people work on the internal construction and decoration, like plasterers, who apply plaster to smooth out walls and ceilings.

© Getty

Site manager

With everybody carrying out separate roles working together to form a complete house, it's down to a site manager to make sure each task is being completed on time.

© Alamy

Quantity surveyor

A quantity surveyor is responsible for tracking finances. This includes calculating the prices for different materials, valuing work once completed and sticking to an overall budget.

© Getty

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THE BUILDING PROCESS

How materials are manipulated and combined to form strong, safe houses

Framing
A wooden skeleton is created to act as a vertical building guide. Pieces of the frame are securely attached using metal strapping.

Waterproofing
A weather-resistant membrane is built beneath the bricks. This waterproof membrane covers every outer area of the house, including the surfaces of the foundations.

Building exterior
Brick walls and other chosen materials are used to build the presentational exterior. This includes design features such as balconies.

Designing for power lines
Holes are knocked into the concrete for power lines to be fed through. Pipes are placed around the cables to protect them.

Watch a two-storey house being built in this two-minute video

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Clearing space
Using bulldozers or other machines, the area is cleared of trees, rocks and debris.

Foundation excavation
A trench with a depth of at least one metre is measured and dug out in the area allocated to the house.

Bricklaying step by step

1 Start at the corners
Place the first bricks at each corner. After laying a few, you will be able to place down a line to see if they have been aligned straight.

2 Mix the mortar
To make the mortar, add five parts sand to one part cement and mix. Then add water to the centre until smooth but still compact.

3 Lay bedding mortar
Place a line of mortar along the string line. This base should be around two centimetres thick. Place the first brick onto the mortar.

4 Build brick pillars
Add more mortar to the end of the placed brick and press the next brick into contact to stick them together. Build the wall up at the pillars.

© Alamy

Steel frames can be used as a stronger and more durable alternative to wood

© Getty

"We need houses to be built to the highest standards"

Preparing utilities
The framework for electrical appliances, plumbing and sewerage can be added into the structure. This involves positioning wiring and pipes.

Designing interior
The interior walls, flooring and other permanent structures such as cabinets are the last to be fitted, and only once the outer structure is complete.

Installing footings
At the very bottom of the trench, concrete slabs are placed. These are called footings, which follow the floor plan to support the house's weight.

Filling the space
Starting at the corners, the bottom of the house's walls are built to just above ground level. Then the remaining trench is filled with a concrete mixture.

5 COMMON BUILDING MATERIALS

1 Wood
Wooden panels give houses a natural look and are relatively easy to cut and shape. This choice requires homeowners to regularly clean and maintain the panels.

© Getty

2 Synthetic stone
This material is made from a mixture of sand, cement and loose stone. It can cover the exterior of housing to look like almost any stone.

© Alamy

3 Stucco
This is a cement-based house siding which contains aggregate for a textured finish. Stucco is long-lasting in dry climates.

© Getty

4 Vinyl
These plastic panels are cheap and can be placed over any existing materials. They are quick to install and come in many different colours and textures.

© Alamy

5 Fibre cement
This combination of cellulose fibres, sand and cement is frost-free and fire resistant. The panels are easy to paint, allowing for a range of designs.

© Alamy

5 Cut to size
When an end requires a smaller brick, use a bolster chisel. Place the brick on its side to create neat, precise cuts.

6 Keep pillars high
Keep the pillar height at least one level higher for stability. Place the centre of each brick over the mortar bond of the bricks below.

© Alamy

7 Add soldier course
A soldier course is when end bricks are placed vertically along the top edge of a wall. This can keep the wall looking tidy.

8 Finishing touches
Use a rounded tool to scrape away any excess mortar. This will keep the sections between bricks looking smooth.

© Alamy

How to stop a hurricane

Could this simple bubble technology reduce the destruction wreaked by these deadly natural disasters?

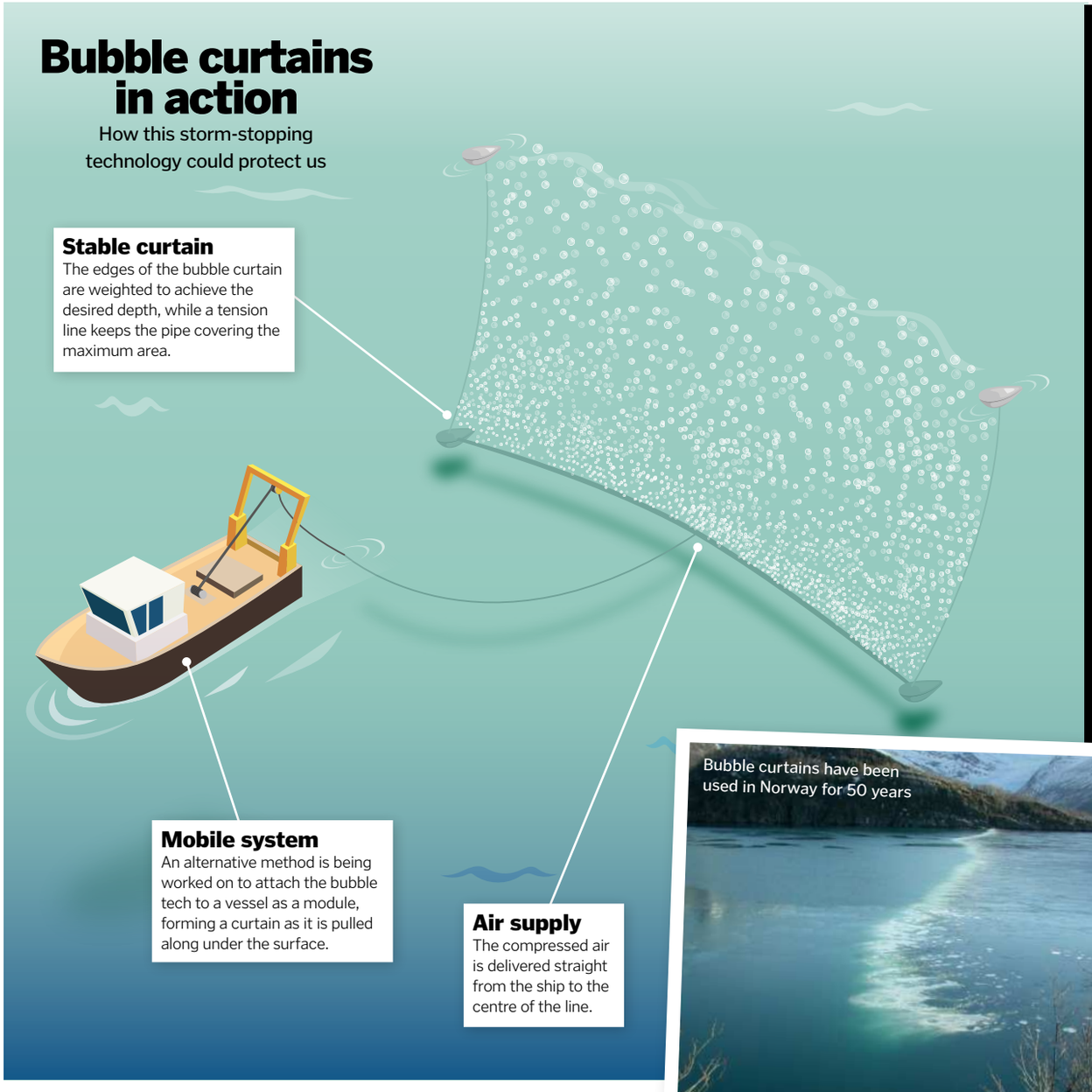
The most recent hurricane season saw a brutal increase in both the strength and number of hurricanes emerging from the North Atlantic. Scientists have concluded that many more of these tropical storms are tearing apart homes and lives as they surge through towns because of the planet's ever-warming conditions. We can all make changes in an attempt to reduce the long-term effects of climate change, but can any immediate action be taken to improve the situation between these killer hurricane seasons?

OceanTherm is one company dedicated to answering this question. Because hurricanes feed off the heat from the ocean's surface, one potential method that aims to calm these tropical storms – or even stop them in their tracks – is to cool the sea using bubble curtains. Bubble curtains are perforated pipes that stretch across the seas, below the surface. As the bubbles released from the pipe travel upwards to the surface, they bring the cooler water up from the deep to lower the temperature of the water at the surface. This technology isn't new, but its application in preventing tropical storms is. Currently, bubble curtains are used in Norway to produce the opposite effect – increasing the surface temperature. As the country's freezing winters often lead to ice forming on the fjords, water hidden from the air's chill is brought up from the depths to prevent it from freezing.

"The bubbles from the pipe travel upwards to the surface"

Bubble curtains in action

How this storm-stopping technology could protect us



Stable curtain
The edges of the bubble curtain are weighted to achieve the desired depth, while a tension line keeps the pipe covering the maximum area.

Mobile system
An alternative method is being worked on to attach the bubble tech to a vessel as a module, forming a curtain as it is pulled along under the surface.

Air supply
The compressed air is delivered straight from the ship to the centre of the line.

Cold bubbles
Cold air rushes to the surface when released, bringing cooler water with it towards the surface. The ocean's natural currents spread the bubbles to a wider area.

At temperatures below 26 degrees Celsius, hurricanes can't form and begin to weaken

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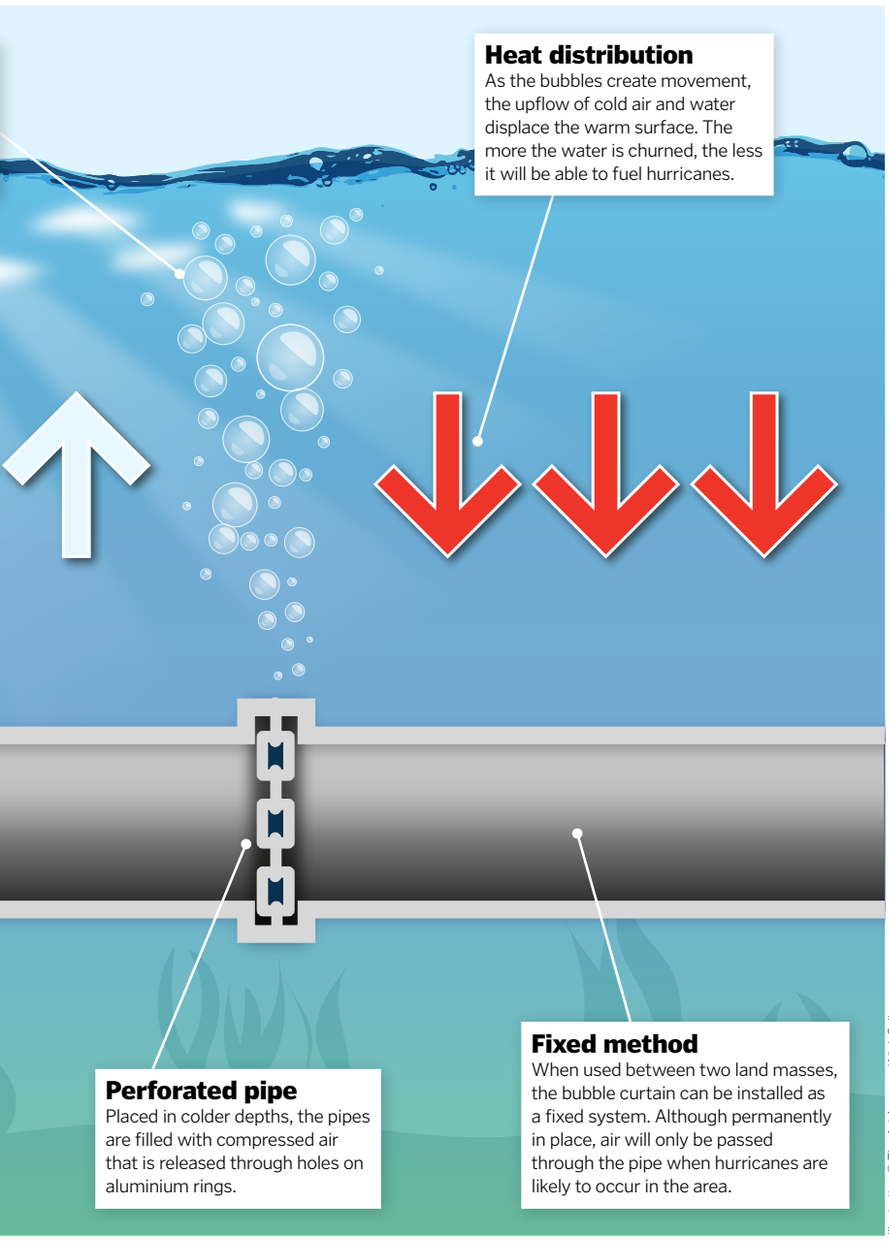


Illustration © The Art Agency / Nick Sellers

Q&A

Oceantherm CEO

© OceanTherm

Olav Hollingsaeter gained a master's in computer science at the University of Bergen and served in the Norwegian Navy before developing his hurricane-halting concept from the existing bubble curtain technology.

When did you come up with the idea to use this technology for hurricanes?
Seeing the devastating damage caused by Hurricane Katrina in 2005 motivated me. With 1,833 lives lost and enormous damage, we all asked ourselves: 'How did this hurricane become so strong?' The warm surface water was feeding the hurricane with energy, making it stronger. As an old submariner, I knew that the temperatures are colder deeper in the ocean column. I started to think about how to lift this cold water.

How much impact could this have on global storms?
Since hurricanes refuel their energy from the warm ocean surface and get an energy cut-off when the sea surface temperature is below 26.5 degrees Celsius, we feel confident that a colder surface layer could prevent tropical storms and hurricanes from increasing in strength – potentially also reducing their strength. This will have a considerable effect on their devastating impact.

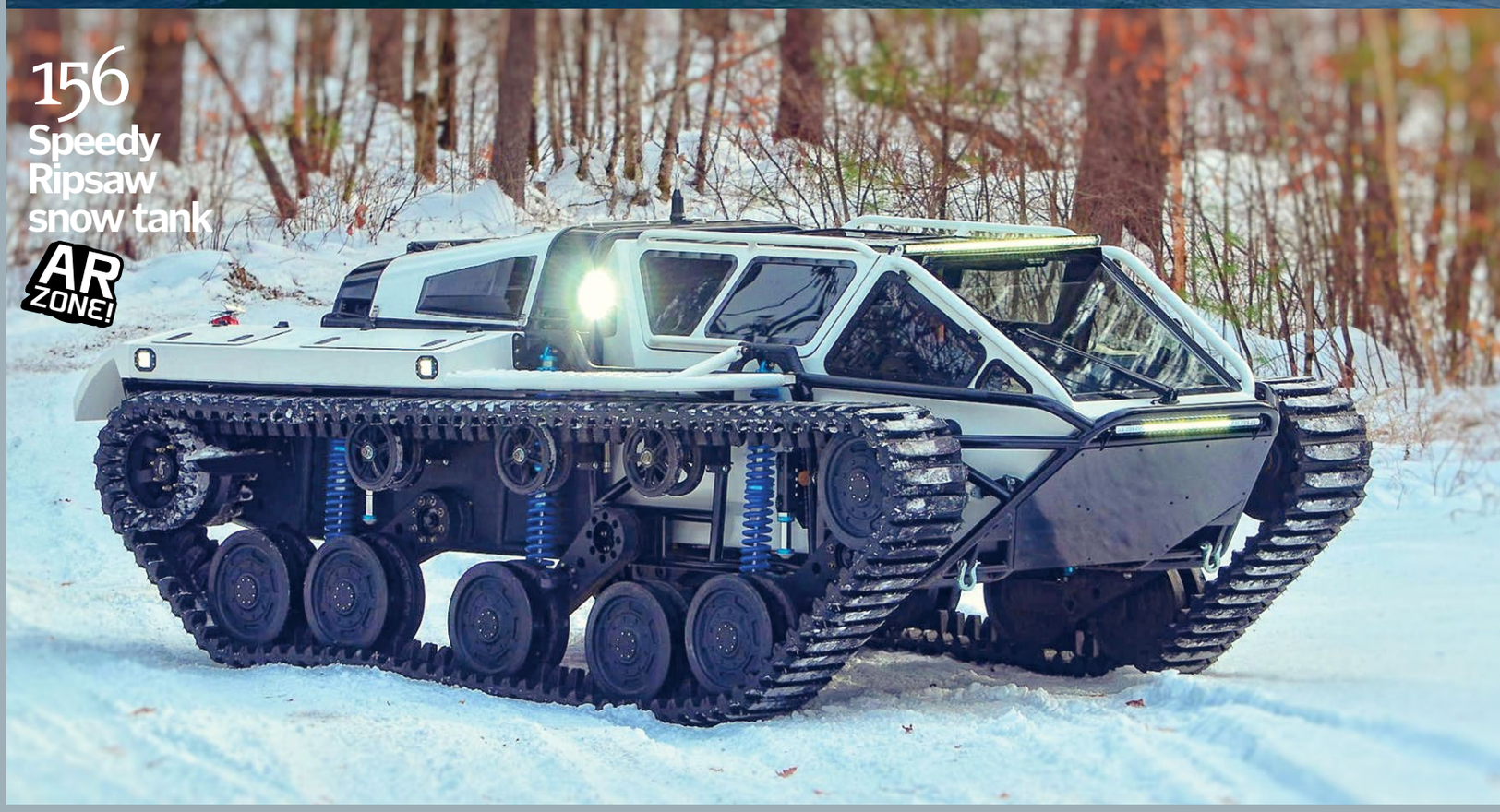
How sustainable is use of the bubble curtain worldwide?
There is a significant climate footprint related to rebuilding after devastating hurricanes, and the flooding and rainfall that come as a result of these devastating storms bring significant pollution back out to the ocean. Preventing this will considerably benefit the climate in addition to saving lives and property. Studies need to assess the effect on the climate and surrounding ecosystems, but we don't anticipate any negative consequences since the cooling is only temporary and very local. The climate footprint of the bubble curtain will be mostly related to the building of the systems and the use of energy when operating the system, which will only be when a tropical storm or a hurricane is coming into an area.

What will make this technology most effective?
The installation will be rather large, including a submerged and moored bubble tube at about 100 metres below the sea surface. To our knowledge, the bubble curtain has never been applied at these depths and in the scale that is necessary for hurricane prevention. Ocean currents will be the true engine in the system, making sure the cooling effect spreads to a larger area. This is necessary in order to have an effect, and really the key to our technology. We help nature to help us. We help nature, by lowering the sea surface temperature, to help us by spreading out the effect with the help of ocean currents.

TRANSPORT

AR ZONE!

146 How to build a warship



156 Speedy Ripsaw snow tank

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HOW TO BUILD A WAR

Words by **Mike Jennings**

The Royal Navy is updating its fleet: here's how it builds its future-proofed, world-class combat vessels

The UK has been known for the strength of its Royal Navy for hundreds of years, and that's unlikely to change any time soon. The organisation has embarked on a program of shipbuilding that's going to modernise its current fleet. It's an expensive, long-term undertaking, but the Navy is certain that its new Type 26 and Type 31 vessels are going to be crucial – and successful – when it comes to maintaining the UK's status as a leading global force. It's not just about keeping the Royal Navy on top when it comes to military hardware, either. The Navy provides humanitarian assistance during natural disasters, protects trade interests and supports the UK's international relationships. It's a broad list of tasks, and new equipment is needed to get these jobs done in the coming decades.

Alongside the carriers in the modern Royal Navy are a range of ships of various sizes, including aircraft carriers and destroyers

SHIP

ready to carry out a wide range of duties around the world, wherever the country needs them. Among them are the frigates, the most populous major warship in the fleet, capable of undertaking virtually every kind of mission around the world. They're the Royal Navy's workhorses.

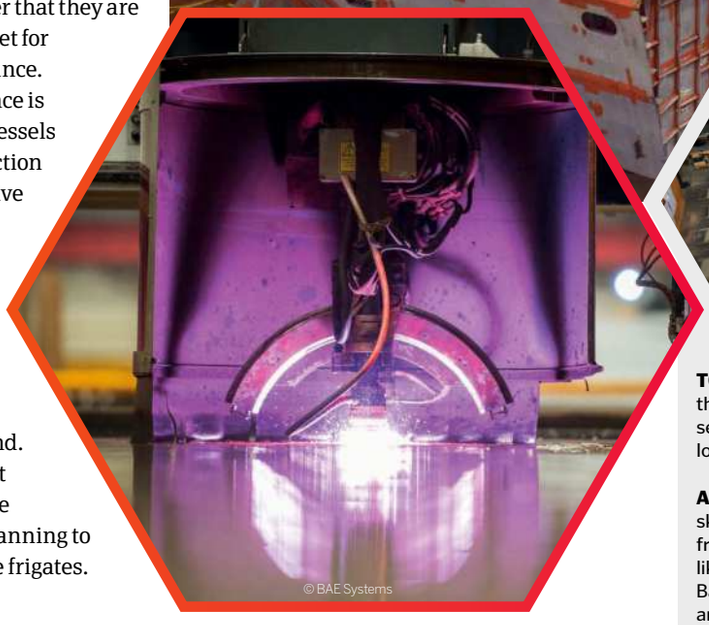
In addition to these core ship classes you'll find several support vehicles – from fuel tankers to patrol boats – and the medical vessel RFA Argus. That doesn't just mean that the Royal Navy needs a large, versatile fleet – it means that the organisation needs to stay on top of the latest technology in order to maintain its position as one of the world's best naval forces.

This is where the Type 26 and Type 31 frigates come in. The Royal Navy is currently in the middle of building these incredible new vessels, and they've been designed to replace the existing Type 23 frigate, otherwise known as the Duke class of ships.


© BAE Systems

These ship upgrades have been planned for a long time. The seeds for the Type 26 were sown way back in 1998, and there were many different designs and plans. But in 2010 things progressed in a big way. The Type 26 emerged from a government defence review and was also described as the Global Combat Ship, with the Ministry of Defence intending to produce ships for the Royal Navy and for export to other countries. It's no wonder that this process takes such a long time when you consider that they are designed to form part of a naval fleet for decades. Nothing can be left to chance.

At present, the Ministry of Defence is planning to deploy eight Type 26 vessels – two are currently under construction and one has been ordered, while five more are planned for the years following. Variants based on the Type 26 design are also being developed for the Royal Australian Navy and the Royal Canadian Navy, and there are partnerships in the works with navies from Brazil and New Zealand. The Type 31 also emerged from that government review in 2010, and the Ministry of Defence is currently planning to order five of these general-purpose frigates.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© Getty

TOP: Components like the bridge are built separately and then lowered onto the ship

ABOVE LEFT: Specialist skills are needed to build frigates, so companies like BAE Systems, Babcock and Rolls-Royce are contracted

ABOVE RIGHT: These communications masts were made in Wales

TYPE CASTING

Let's start with the Type 26 – the biggest and more expensive of the two new ships. It's going to tackle a wide range of tasks that face the Royal Navy now and in the future. The new vessel will use a modular design that will enable it to be built to differing configurations and to be more easily fitted with new components in the future.

The Type 26 will have a 3D search radar, 48 launching systems for air-defence missiles, anti-submarine rockets, anti-ship missiles and other weaponry, and it'll have an acoustically dampened hull to make it harder for submarines to spot the ships. There's a dizzying array of technology on board elsewhere, including sonar arrays, naval guns, gas turbines and electric motors, alongside diesel generators and room for high-end Merlin and Wildcat helicopters.

It's a fearsome amount of kit, and these Type 26 ships come with a suitably impressive list of statistics. The Type 26 frigates will be called the

THE TYPE 26'S COMPUTERS CARRY AS MUCH DATA AS 1.5 MILLION TV CHANNELS

SHIP-BUILDING SITES

Most of the Type 26's exterior building work is taking place at BAE Systems' Ship Block and Outfit Hall at Govan in Glasgow, and BAE has invested more than £100 million (about $135 million) in its facilities at Govan and Scotstoun to support the manufacturing program. Unsurprisingly, building ships like this is complicated, which means that several different facilities are being used. The Type 26's individual modules are being constructed at a dedicated fabrication facility at the Govan shipyard, and the fore and aft sections of the ship will be built separately. Once they're done, the two sections will actually leave the huge halls that are usually associated with shipbuilding, and they will be connected and then topped off with the funnels, mast and bridge while the vessel is outdoors. Unusually, that means that two-thirds of the Type 26's construction time will be spent outside.

©Getty

The BAE Systems shipyard in Govan, Glasgow, where the first Type-26is being finished

BUILDING A BATTLESHIP

Building a frigate like the HMS Glasgow is a complex process

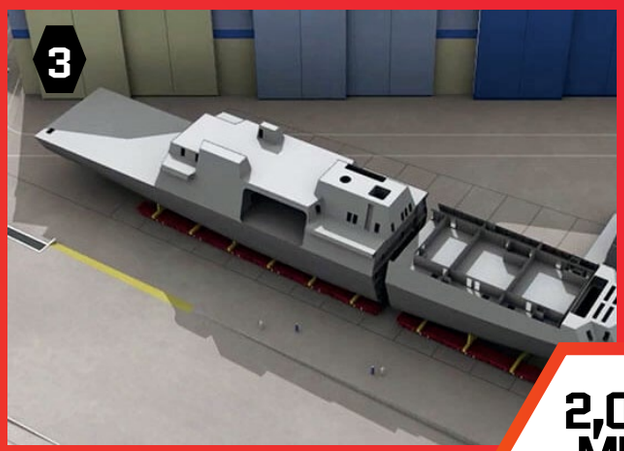
1 Piece by piece
The first stage of the building process involves constructing parts of the ship in smaller sections – modules that will house the ship's various rooms, facilities and equipment.

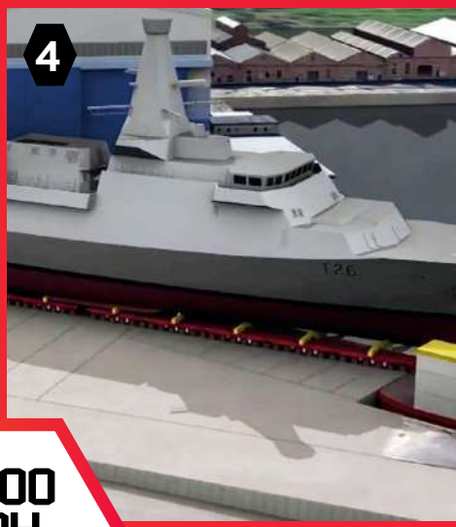
2 Joining forces
Once the modules are built, they're combined into the larger front and rear sections. These will leave the shipbuilding hall in Glasgow and sit in front of the vast building.

3 Building bridges
The two halves of the Type 26 will be lined up outside of the shipbuilding hall along with other components like the bridge and mast, which are constructed elsewhere.

4 Topping it off
The fore and aft sections are joined together, and then the components like the mast, bridge and funnels are lifted onto the ship by crane and installed.

5 Hitting the water
A special barge is used to move the ship from the dockside and into the River Clyde, and it'll be towed to another shipyard for the internal kit to be fitted.





2,000 MPH
The Type 26's anti-air missiles travel at incredible speed

© BAE Systems

THE TYPE 31'S INNOVATIVE MANUFACTURING

The Type 31 frigate shares its modular approach with the Type 26. This design strategy is a key part of the UK's approach to shipbuilding, and it allows ship designs to be tweaked and upgraded – and sold to other countries. These smaller ships are being built by Babcock International rather than BAE Systems, and Babcock is spending £50 million (about $70 million) on a new hall to construct these vessels. Individual ship modules will be rolled into this new hall on self-propelled transporters, moved into position using cranes and then attached to other modules. Once the ship's hull is complete, it will be moved outdoors so the mast, bridge and other components can be fitted – just like the Type 26.

The Type 31 is produced in modules, just like the Type 26, for easier building

© MOD

City class. These City-class ships will be 149.9 metres long and have a displacement of 6,900 tonnes – and that will increase to more than 8,000 tonnes once they're fully loaded. Those huge numbers mean that these vessels will be the length of one-and-a-half football pitches and weigh almost as much as the Eiffel Tower. The ships will have a range of 7,000 nautical miles and a standard crew complement of 157 that can be increased to a maximum of 208.

The first Type 26 is called the HMS Glasgow in honour of the city where it's being built. The next two frigates will be called HMS Cardiff and HMS Belfast, and the five that are planned beyond that are also going to be named after other cities in the UK. The innovative modular design is already paying off. Australia's vessels will be called the Hunter class. They're going to be heavier and support a larger crew than the UK's ships, with a different array of guns. The Canadian Surface Combatant ship will be a little longer than the other two, with different sensor systems and weapons and an even larger crew.

"THE NAVY'S NEW FRIGATES ARE IMPRESSIVE, EXPENSIVE AND COMPLEX"

Mid-range muscle
The Type 31 has a flight deck, just like the Type 26, but this ship only accommodates smaller helicopters.

Shared characteristics
The front of the Type 31 features a bridge, ops room and a gun – just like the Type 26.

Flight hangar
Both new ships have flexible mission bays and secondary flight hangars, but they're smaller on the Type 31.

© MOD

THE NEW FRIGATES EXPLORED

The new frigates are packed with impressive hardware

Sonar
The bow of the ship deploys a submarine-detecting sonar system that can scan the ocean for miles around.

15 miles
The Type 26's pipework would be three-times taller than Mount Everest if stood upright

Right on target
The 12.7-centimetre gun has a range of 20 nautical miles, and could be used with smart ammunition in the future.

In control
The ship is commanded from the bridge and the operations room. An open architecture means that upgrades are easier.

© MOD

© MOD

World-leading versatility
All sorts of hardware can be stored in the mission bay, from boats and vehicles to supplies for disaster relief.

The 6.5-tonne turbine is paired with electric motors and diesel generators

© Rolls-Royce

QUIET, FAST AND FUNCTIONAL

One of the Type 26's main functions is to combat the threat of submarine attacks, and that means this frigate needs a unique set of technologies. The threat of underwater attack means that the propulsion system has been designed with stealth in mind, so the vessel's Rolls-Royce MT30 gas turbine is combined with electric motors to reduce noise. Elsewhere, the Type 26 has special pipework, shock-resistant mounting and acoustic enclosures to reduce noise. The hull is shaped and lined in order to cut back on noise output, too. All of these features combine to make the Type 26 quieter and stealthier than any Navy ship before it – important when defending on the high seas.

High-end weapons
The Type 26 has sophisticated anti-air defence systems, and its radar offers unrivalled protection for detecting threats and jamming cyber attacks.

© MOD

TYPE 26 FRIGATES WILL BE BASED AT HMNB DEVONPORT, PLYMOUTH, IN SOUTHWEST ENGLAND

Air and sea options
At the rear is a flight deck, which can house a large helicopter for missions away from the ship.

Silent sailing
The frigate is powered by a Rolls-Royce gas turbine and diesel generators, and the hull is designed to reduce noise.

© MOD

© MOD


© BAE Systems

The Type 31 frigates are around ten metres shorter than the Type 26 vessels, and they're a little lighter. They'll need a smaller crew of around 100, and they have fewer weapons systems, but they're faster, and have a wider range. Unsurprisingly, these ships aren't cheap. The Royal Navy, the Ministry of Defence and the government spent plenty of time wrangling over designs and costs, but the first order of three Type 26 frigates came in 2017 for £3.7 billion (about $4.9 billion) – so they're working out at more than £1 billion (around $1.35 billion) per ship. The smaller Type 31 ships cost around £250 million (about $340 million) each.

THE SHIP'S CREW QUARTERS INCLUDE RECREATION AREAS AND A GYM

© Rolls-Royce

BUILDING BLOCKS

There's no doubt about it, the Type 26 and Type 31 frigates are impressive. But they're also expensive and complex, and the Royal Navy doesn't build them itself. Because of the specialist equipment and skills required, they hire shipbuilding firms to take on the mammoth task. The Type 26 frigates are being built by BAE Systems, and more than 40 other suppliers are producing components, including Rolls-Royce – the entire process supports more than 3,000 jobs.

The first of the UK's Type 26 ships is under construction at BAE's Ship Block and Outfit Hall in Glasgow. The modular design means that the ship is being built in huge blocks which go together to form the front and rear halves of the ship – in nautical terms, they're the 'fore' and 'aft' sections. Those sections are pieced together, all of the piping and cabling is linked up and then the hull of the HMS Glasgow will be structurally complete. Once that's done, the funnels, mast and bridge will be lifted onto the hull by cranes and attached securely. During 2021 the entire vessel will be rolled onto a huge barge that will be used to lower the ship into the water of the River Clyde.

Once the ship is lowered into the river, it's going to be towed down the River Clyde to another BAE shipyard at Scotstoun. It's here where the vessel will be 'fitted out', meaning that the rest of the construction will be finished. This part of the process mostly involves kitting out the interior of the ship. It's planned that the first Type 26 frigate will be accepted by the Royal Navy in 2025, becoming operational by 2027. The first Type 31 ships are also planned to be operational by 2027.

ABOVE: The front and rear sections of the ship are built separately, then connected outside

RIGHT: The frigate's mission bay can hold boats, supplies or other vehicles – whatever is necessary

"THE FIRST TYPE 26 IS CALLED THE HMS GLASGOW"

ROYAL NAVY SHIPS THROUGH THE AGES

1511 – MARY ROSE
RN ship type: Carrack
The Mary Rose was King Henry VIII's flagship. It served for 33 years, but sank near the Isle of Wight.


© Alamy

1637 – SOVEREIGN OF THE SEAS
RN ship type: Ship of the line
This fearsome flagship – nicknamed 'Golden Devil' – was the first vessel with three gun decks, since King Charles I demanded more firepower.


© Getty

1765 – HMS VICTORY
RN ship type: Ship of the line
The Royal Navy's most famous vessel was Nelson's flagship at the Battle of Trafalgar, and is today docked in Portsmouth.


© Alamy

1820 – HMS BEAGLE
RN ship type: Brig-sloop
This survey ship was famed for carrying naturalist Charles Darwin on his influential voyages around the world.

1891 – HMS ROYAL SOVEREIGN
RN ship type: Battleship
This 14,150-tonne vessel was the largest warship in the world when built. It was eventually sold for scrap.

1906 – HMS DREADNOUGHT
RN ship type: Battleship
This was the fastest and best-armed battleship in the world at the time. It made other ships immediately obsolete because of its firepower.

Q&A DIRECTOR FOR TYPE-26 FRIGATES

Rear Admiral Paul Marshall CBE, the senior officer responsible for delivering these latest warships, explains their role in the Royal Navy

Rear Admiral Marshall has embarked on naval tours to Asia, the Caribbean and Africa

How will the Type 26 and Type 31 frigates fit into the current Royal Navy fleet?
The larger Type 26 is an advanced anti-submarine warfare warship designed to support the UK's other vessels. As well as protecting us from submarines, the Type 26 will support operations across our full spectrum of tasks, including counter-piracy missions, disaster relief work and delivering humanitarian aid. It's going to be around for a long time – the Type 26 is designed for a service life of 25 years, so it'll be an essential component of the Royal Navy fleet into the 2060s.

The Type 31 will also be at the heart of our fleet – deterring aggression, maintaining the UK's interests and helping those in need. The Type 31 is designed to relieve the operational pressures on other ships, including the Type 26, so those vessels are freed up to tackle specialist tasks. That means the Type 31 doesn't have the anti-submarine features that are included on the Type 26.

What weapons will the Type 26 be equipped with when it launches, and what will be added in the future?
The Type 26 has a flexible design that will enable its capabilities to be adapted throughout its life span in order to counter future threats. The HMS Glasgow will enter service with a Sea Ceptor air defence missile system and a 12.7-centimetre medium-calibre gun. The Type 26 can also embark with a Merlin anti-submarine helicopter or a Wildcat maritime attack helicopter. The Wildcat will be able to deploy two variants of our Future Anti-Surface Guided Weapon.

The Type 26 frigate will be fitted with the Mark 41 Vertical Launching System, which provides the flexibility to field a variety of weapons, and that may include our next generation of ship-launched strike weapons. The Type 26 is inherently flexible, which allows us greater choice when planning operations and upgrades. That's important because it allows us to upgrade the ship's systems throughout its lifetime so it can tackle future threats.

What sort of facilities will be included for the crew on the HMS Glasgow?
As with all warships in the Royal Navy, the Type 26 will be fitted with a sickbay and ward. A number of our personnel are trained in first aid, and depending on the mission we'll have specialist medical personnel on board. When operating as part of a larger strike group, personnel will have access to a wider range of equipment and staff.

In addition, the Type 26 will be fitted with a gym that includes weightlifting and cardio equipment, and a physical trainer will be part of the ship's crew so they can provide the crew with specific training programs and guidance on healthy eating.

The crew's accommodations have recreation areas with TVs and games consoles, and social areas for people to congregate. There will be a library, and personnel can also access a range of TV and radio stations through the British Forces Broadcasting Service.

HMS WARSPITE
RN ship type: Battleship
A vessel that served in both World Wars, thanks to extensive modernisation and a stellar design. It was a Queen Elizabeth-class ship, reaching speeds of 23 knots.

1913

HMS FURIOUS
RN ship type: Battlecruiser
The Royal Navy's first aircraft carrier happened due to design changes – it was originally designed as a conventional cruiser before its forward turret was replaced with a flight deck.

1916

© Getty

HMS HOOD
RN ship type: Battlecruiser
This famous but flawed ship was infamously sunk by the German battleship Bismarck in 1941.

1918

© Alamy

HMS DREADNOUGHT
RN ship type: Submarine
The second HMS Dreadnought was the UK's first nuclear submarine, and was launched on Trafalgar Day.

1960

© Alamy

HMS INVINCIBLE
RN ship type: Aircraft carrier
This aircraft carrier was the flagship of the Royal Navy's fleet and saw action in several wars.

1977

© Alamy

HMS QUEEN ELIZABETH
RN ship type: Aircraft carrier
This new flagship aircraft carrier is the Royal Navy's largest-ever warship and can carry more than 60 aircraft.

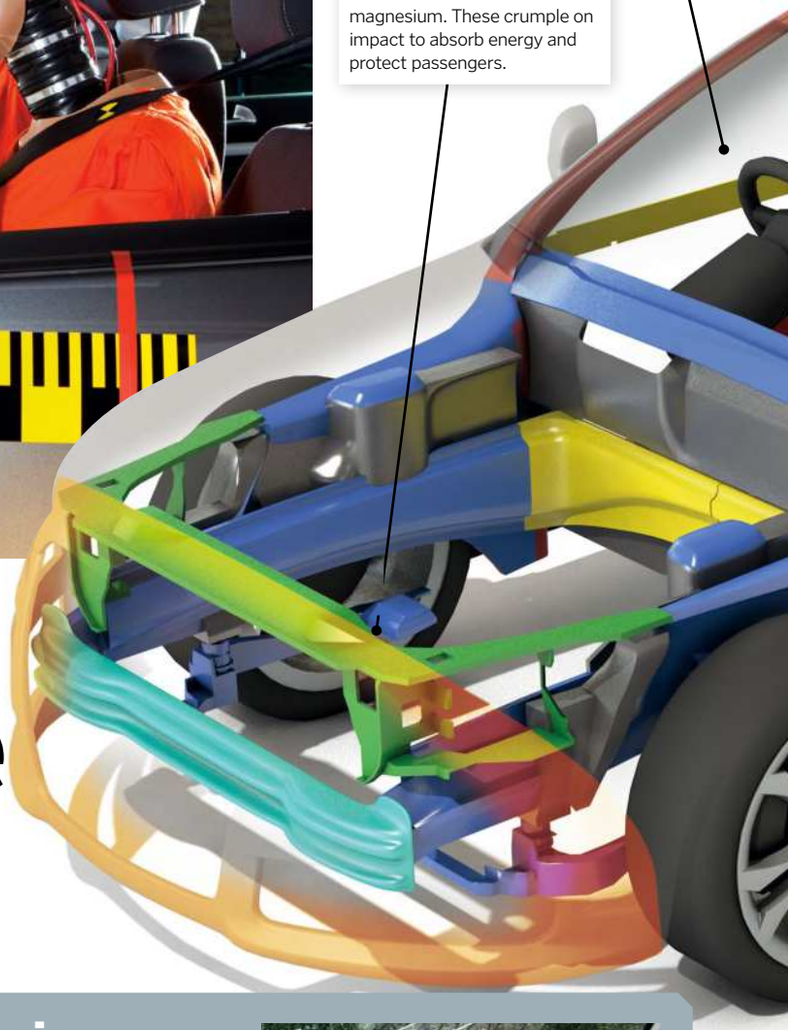
2017

Cars are packed full of safety features and undergo strict testing

© Getty

Framed glass windows
Glass used in cars is designed to stay intact or fracture into rounded fragments so passengers aren't hurt by sharp shards.

Taking the impact
Many cars include panels made from metals like aluminium and magnesium. These crumple on impact to absorb energy and protect passengers.



How cars keep you safe

Delve beneath the bonnet to discover the impact manufacturers are making on car safety systems

Words by **Mike Jennings**

It's easy to forget when cars are integral to our everyday lives, but think about this for a second: they're metal boxes that can drive at excessive speeds to transport human bodies made of fragile flesh and bone. Safety is crucial. That means every part of a modern car is designed with protection in mind, from the engine to the bumpers and everything in between. And with safety so important, some parts of a car get more attention than you might initially expect. Let's look at the doors and side panels as an example.

These parts of a car are often closest to the driver and passengers, so they've got to be sturdy. To that end, car manufacturers have developed side-impact designs that include incredibly strong steel panels, extra metal inside the doors to brace against impacts and columns to help cars keep their shape during collisions.

A load of hot air

Airbags are one of the most common and crucial safety features found in modern cars, and they've been around for a long time – they were first fitted to cars in the 1970s. In modern cars, airbags are controlled by a little computer with an accelerometer that detects if there's a sudden change of speed. If a car decelerates quickly enough, the computer ignites a tiny propellant that generates nitrogen gas to expand into the airbag. This forces the bag out of its casing and into the car, where it cushions people from sudden dangerous collisions, and then the nitrogen gas escapes from the bag.

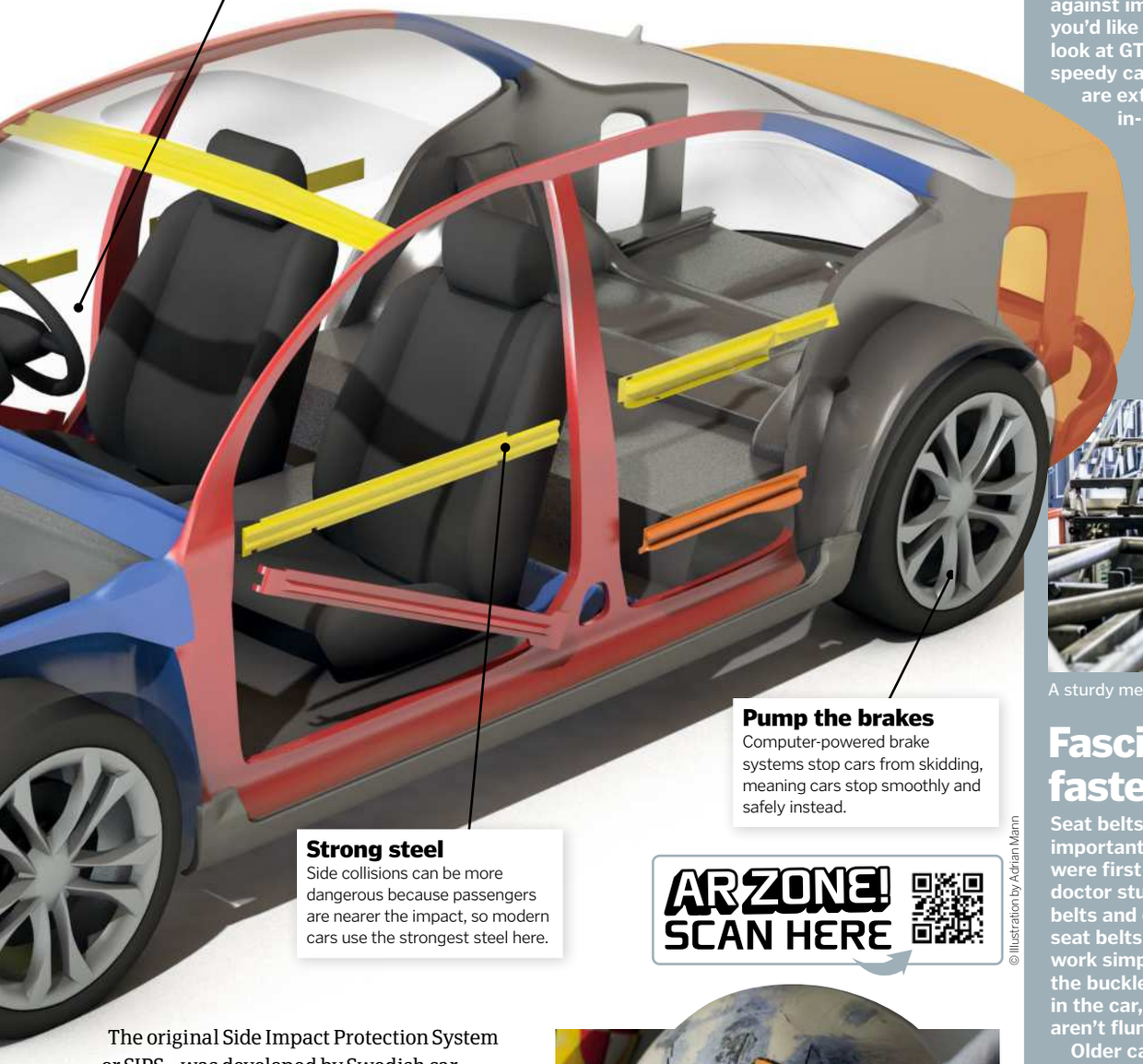
Airbags work because of incredibly fast chemical reactions, and they're used all over modern cars: they can usually be found in the steering wheel, the doors and side panels, towards the floor of the vehicle to protect people's knees and even in the roof.

© Getty

Airbags for use in automobiles were patented by John W. Hetrick in 1952

Safety first

Here are five key safety features that you'll find in most modern cars



Steered from danger
The metal that holds the steering wheel collapses in accidents so that drivers aren't thrust forward into a static column.

Strong steel
Side collisions can be more dangerous because passengers are nearer the impact, so modern cars use the strongest steel here.

Pump the brakes
Computer-powered brake systems stop cars from skidding, meaning cars stop smoothly and safely instead.

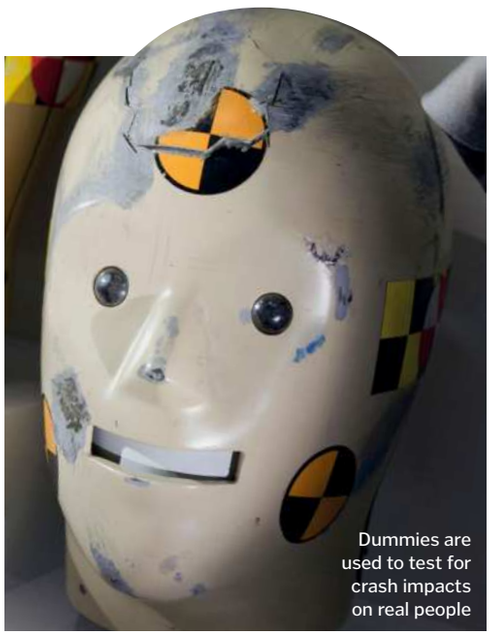
AR ZONE! SCAN HERE

© Illustration by Adrian Mann

The original Side Impact Protection System – or SIPS – was developed by Swedish car manufacturer Volvo and started appearing in its cars in the early 1990s. Volvo still includes SIPS technology in its cars, as does every other manufacturer with equivalent safety designs, albeit under different names.

Go beyond the sides of a car and you'll find an incredible array of safety features that protect every inch of a modern motor. Designers first started to incorporate basic impact protection into cars in the 1930s, and since then vehicles have become safer and far more sophisticated.

These days car safety features are organised into two camps: passive features like the car's frame, airbags and seat belts protect passengers after a collision, while active features like cameras, sensors and brakes work all the time to keep the car stable.



Dummies are used to test for crash impacts on real people

© Alamy

Roll cage

The roll cage is a giant, strong metal frame that surrounds the passenger compartment, which helps protect against impacts from any direction. If you'd like to see a roll cage in action, just look at GT and touring car racing. These speedy cars have big, tubular cages that are extremely obvious when you see in-car footage.

Not every road-going car has a roll cage built in though. While these cages do improve safety, they add weight and therefore hamper fuel efficiency. Manufacturers can make their vehicles safe using other methods, like stronger roof panels and other structural additions throughout the design.

© Getty

A sturdy metal roll cage is vital in many vehicles

Fascinating fastening

Seat belts are one of the oldest and most important safety features in cars. They were first introduced when a Californian doctor studied the links between seat belts and collision injuries, finding that seat belts made a huge difference. They work simply: the belt secures tightly into the buckle, and when a crash is detected in the car, the belt tightens so people aren't flung forward.

Older cars used seat belts that just stretched horizontally across passengers, but modern cars use three-point designs that also cover the chest area. That system does a better job of spreading energy out during impacts, which keeps people safer.

© Getty

Seat belts are simple, but they're life-saving safety devices

AR ZONE!

Speedy Ripsaw snow tank

How the world's fastest dual-tracked vehicle works

Off-road driving can be invigorating in most circumstances. But as you cover increasingly unreliable ground, how much trust can you put in your vehicle to safely continue its journey? The bumpy and disorderly drive you would expect to experience when travelling over rocky obstacles and deep snow disappears when inside the Ripsaw tank.

Designed by Howe & Howe Technologies, the Ripsaw EV3-F4 is described as the 'Floating Cockpit', and claims to be able to cover any terrain. As its occupants sit high atop the tracked wheels, travelling at up to 60 miles per hour across rough ground, you can see why this beast is described as such. With an array of windows to keep the driver and passengers fully immersed in their surroundings, the tank glides with ease over even the most treacherous terrain types.

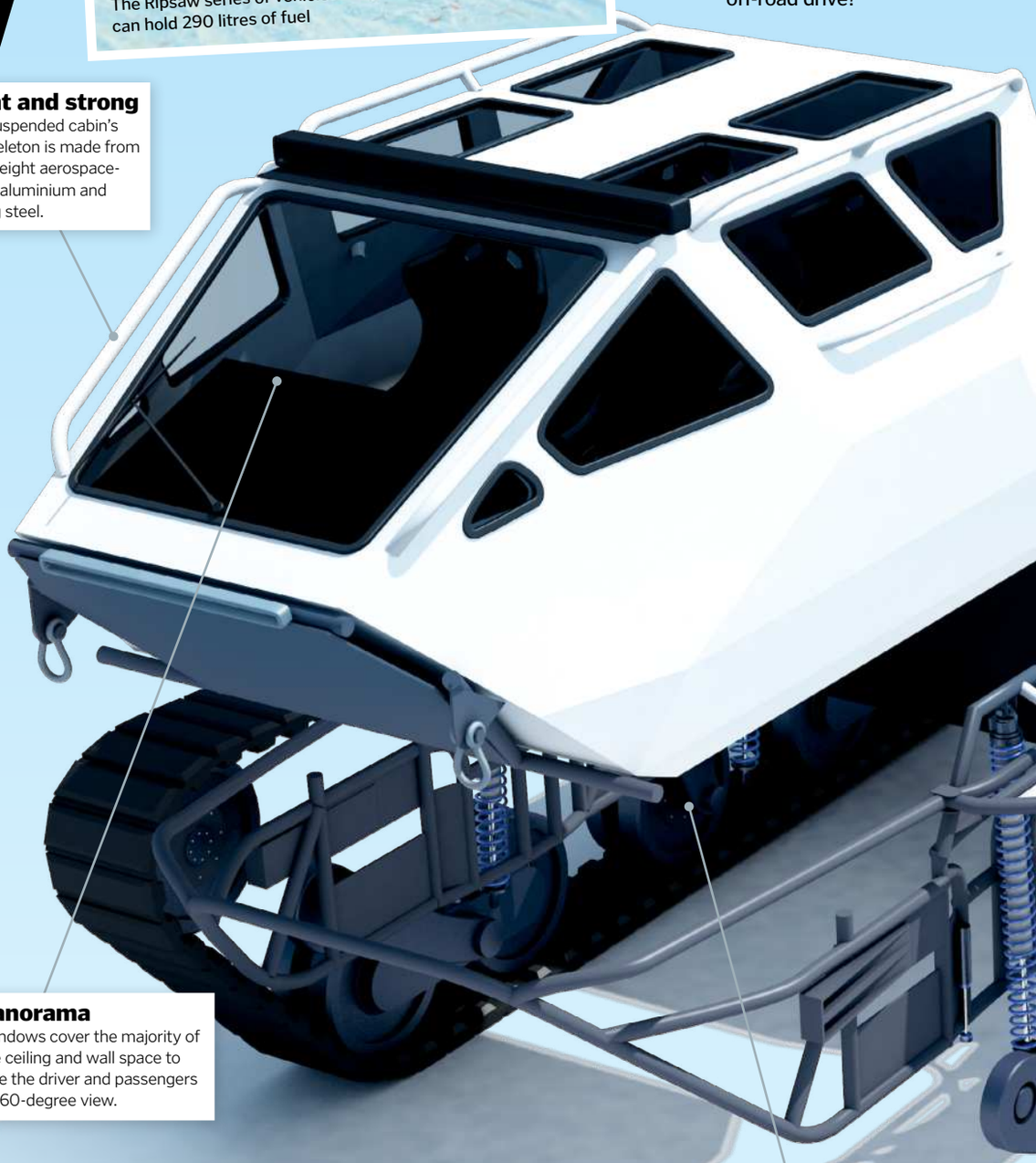
Ripsaw vehicles caught the eye of the military, and the US Army used them to traverse various war zones during defence, surveillance and explosive disposal missions. However, today these mighty specimens are also available for civilians to purchase.

Due to the increasing number of variations being produced through customisation, the price tag can vary. But all you need to boast about having your own all-terrain tank is around £500,000 ($675,000) and some epic, off-road terrain to show off on.

The Ripsaw series of vehicles can hold 290 litres of fuel

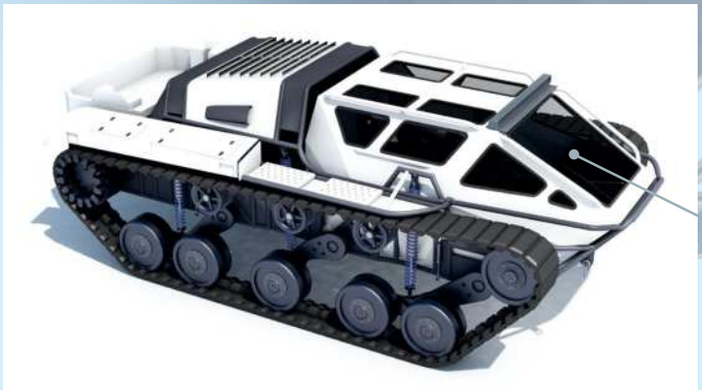
Riding the Ripsaw F4

What technology produces this smooth off-road drive?



Light and strong
The suspended cabin's exoskeleton is made from lightweight aerospace-grade aluminium and strong steel.

Panorama
Windows cover the majority of the ceiling and wall space to give the driver and passengers a 360-degree view.



4,500 kilograms
Despite its bulk, this tank maintains speed and manoeuvrability, with a minimum turning radius of just 2.4 metres. A passenger car has a turning radius of around ten metres.

Passenger potential
While earlier models had limited passenger space, this commercial variant allows three people to ride alongside the driver.

Luxury controls
The heated steering wheel comes with paddle shifters for quick gear changes.

Digital dashboard
This dual display presents data such as live images from the 360-degree cameras.

Power to weight
The vehicle produces a power of over three kilowatts per kilogram.

Clearance
There's 50 centimetres between the ground and the passenger pod.

Constant contact
284 centimetres of rubber track covers the ground at all times to increase traction on the slippiest surfaces.

AR ZONE! SCAN HERE

The tank's tale

The first variant of the vehicle was created 20 years ago by Michael and Geoff Howe, founders of Howe & Howe Technologies. The twin brothers aimed to create the fastest tracked vehicle ever designed, and targeted their product for army use. After the military adopted it, largely utilising its remote-controlled capabilities for unmanned missions, the Ripsaw soon gained public interest.

Though the brothers originally declined offers from civilians, they later realised the possibilities. Being based in the US, the majority of interest in the vehicle comes from ranch owners with a bit of space to play with. After all, there's a reason that this vehicle is classified as 'off-road', with its unstoppable nature making it illegal on public roads.

Owners often customise their tank with stand-out colours and interior changes

Hydrogen: the future of cars?

We're heading towards a greener future, which could mean switching from petrol to hydrogen power

Our planet's changing ecosystem means that our cars need to change too, which is why electric cars have become popular and why hydrogen fuel cells are now being touted as another option for green motoring. There's plenty of good news. For starters, there's a lot of hydrogen about: it's Earth's most common element and it can be extracted from water, natural gas, biomass and several other sources. It's not toxic, in theory there's an almost unlimited supply and vehicles powered by hydrogen only emit water and heat, not harmful greenhouse gases.

Hydrogen cars have an impressive range when compared to electric vehicles, often matching conventional cars, and they can be refuelled in five minutes. That compares well to electric cars, which take hours to charge. They're quiet, too.

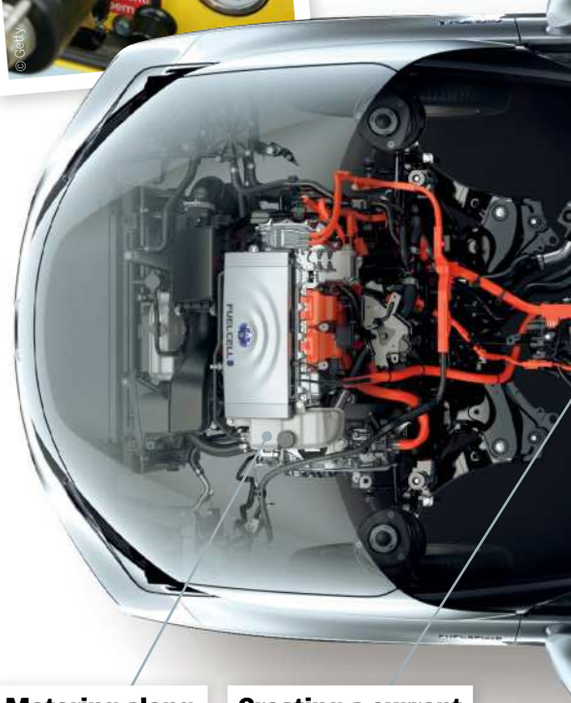
But the bad news is significant. Hydrogen can be efficient, but lots of fossil fuels are currently used to create hydrogen – and that undermines everything. That will have to change if hydrogen is to become viable, but biomass, solar, wind and other renewable sources are being developed.

There are also questions around efficiency elsewhere. Positively, however, the US Department of Energy estimates that conventional petrol engines run at around 20 per cent efficiency, while hydrogen fuel cell engines are between 40 and 60 per cent efficient. That's great, but more energy is required to compress, transport and store hydrogen, and renewable methods used to produce hydrogen may not always be very efficient.

There's not much in terms of infrastructure, either, with only around 20 filling stations in the UK. At least 100 will be needed to provide the bare minimum of national coverage. If you want a stark comparison, consider that there are more than 37,500 electric charging points across the UK. While hydrogen fuel cells are an exciting option, there's still a long road ahead.

© Getty

Filling stations need to be built for hydrogen, or existing facilities need to be refurbished



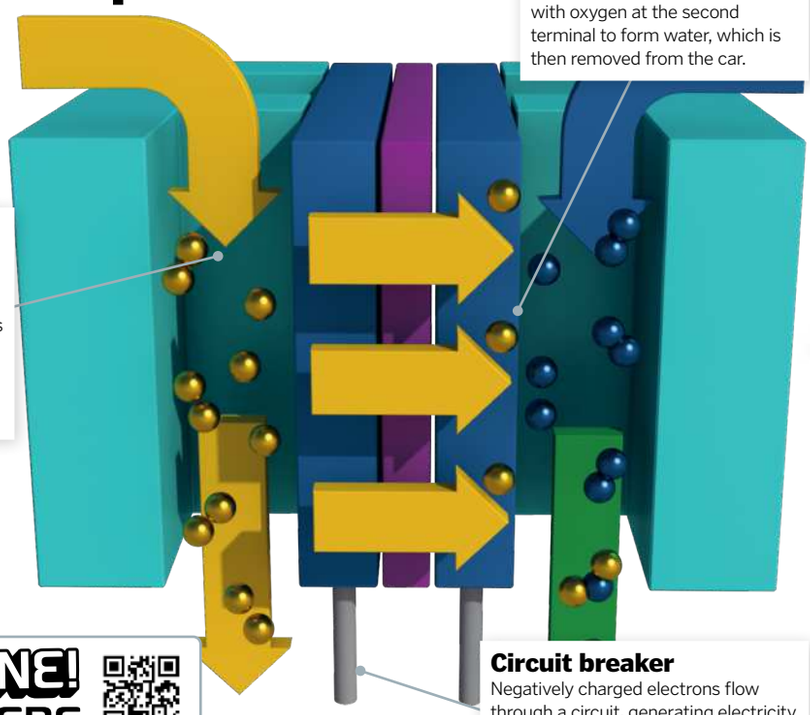
Motoring along
Motors used by hydrogen cars are often the same as those in battery-powered vehicles – the power method is just different.

Creating a current
The converter changes the fuel cell's high-voltage electricity to a lower voltage that the car can use.

Play it cool
Heat is produced by fuel cells, so air flows through the front of the car to keep everything chilled.

Fuel cells explained

Here's how hydrogen fuel cells work and how they function inside new cars



Separate charges
Hydrogen is separated into protons and electrons at a terminal called the anode, and a catalyst accelerates the process.

A positive outcome
Electrons and protons combine with oxygen at the second terminal to form water, which is then removed from the car.

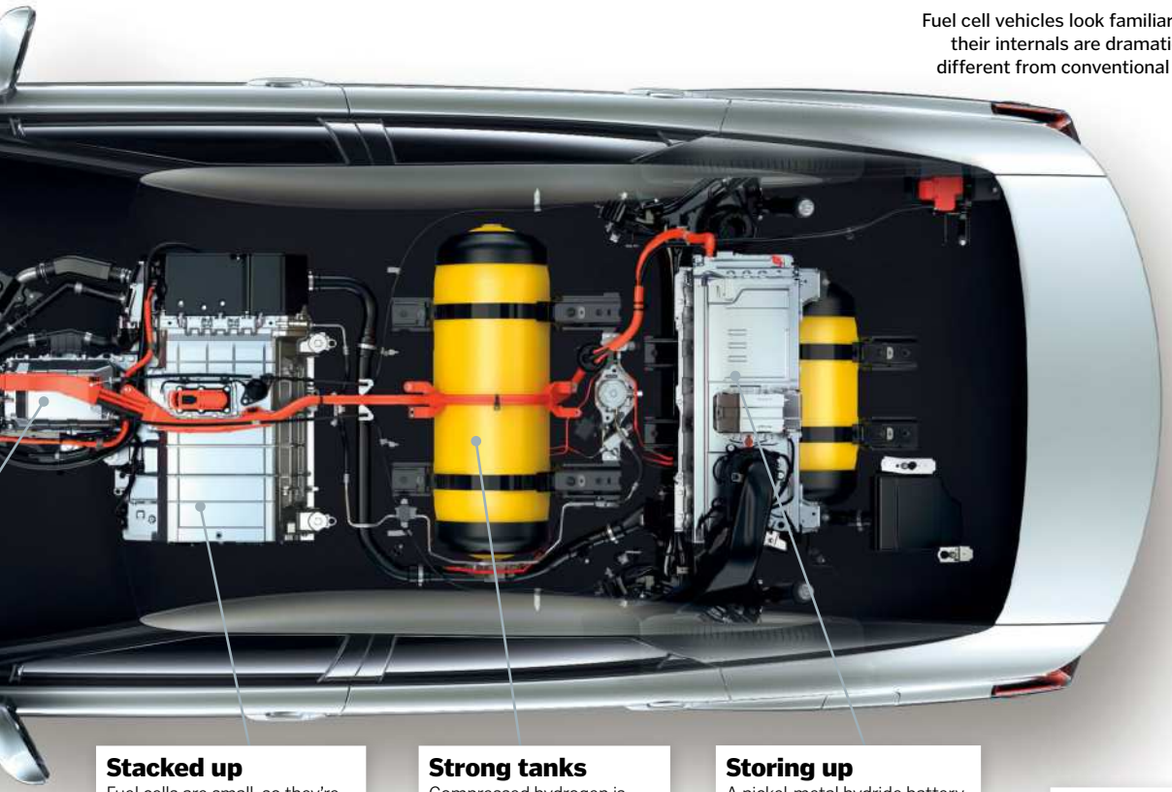
Circuit breaker
Negatively charged electrons flow through a circuit, generating electricity that is used to power the motor.

AR ZONE! SCAN HERE

© Illustration by Adrian Mann


© Getty

Fuel cells started life in laboratories, but this futuristic technology is powering cars



Stacked up
Fuel cells are small, so they're arranged in stacks that provide combined power – the latest Toyota Mirai uses 330 cells.

Strong tanks
Compressed hydrogen is stored here until it's needed. Hydrogen is explosive, so these have to be very strong.

Storing up
A nickel-metal hydride battery assists the fuel cell stack during acceleration, and stores energy from deceleration.

Gas-guzzler
Filling the tank is easy – the nozzle establishes a seal to maintain pressure, and it takes about five minutes to fill.

© Toyota

Fuel cell vehicles look familiar, but their internals are dramatically different from conventional cars

© Toyota

5 FACTS ABOUT THE HEADY WORLD OF HYDROGEN

1 Early beginnings
The first hydrogen fuel cell charging station opened in Swindon in 2011 at Honda's manufacturing site. It served the FCX Clarity, Honda's first hydrogen car.

2 Lighter than air
Hydrogen fuel cells aren't just used in cars – they've been used in space rockets, and they could be used to power buildings, trucks and even planes.

3 Filling the gaps
The UK may need more hydrogen infrastructure, but other areas of the world are doing better – there are dozens of filling stations in California, with over 100 more to be built by 2027.

4 Heavy lifting
It's estimated that more than 53,000 hydrogen fuel cell vehicles were being used globally by the end of 2020, including around 31,000 forklift trucks.

5 Big-name involvement
Mercedes produced the first road-legal fuel cell car in 1998, BMW is developing a concept SUV and Jaguar is aiming to produce a Range Rover that uses fuel cells.

A lot of hot air?

Just two hydrogen-powered cars are sold in the UK, and they're both pricey – the Hyundai NEXO and Toyota Mirai cost more than £60,000 ($83,850). Despite that, a handful have been sold. The Metropolitan Police, the National Trust and a major rental car company have already added some to their fleets. Some bus fleets also use hydrogen fuel cell vehicles.

Toyota expects its cars to cost the same as its hybrid models by 2025. Elsewhere, BMW and a dozen other companies have committed to $10 billion (£7 billion) worth of investment in the next decade, and Toyota reckons that every major car manufacturer will soon be working on hydrogen-based hardware. Experts think that hydrogen gaining ground is inevitable: it'll have to play a part if the UK government is going to meet its pledge to make the country carbon-neutral by 2050, and we've already got a great natural infrastructure for generating hydrogen.

© Toyota

The Toyota Mirai is available in the UK, but it can only be filled at a handful of stations

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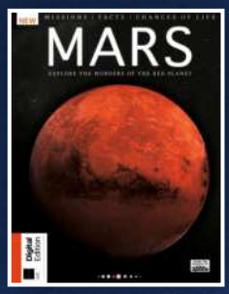

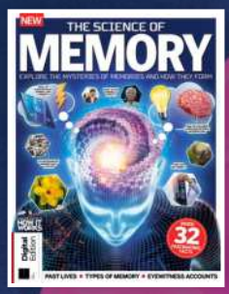

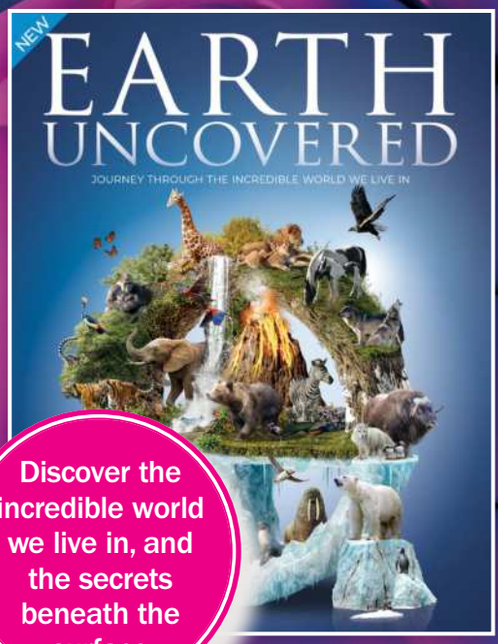

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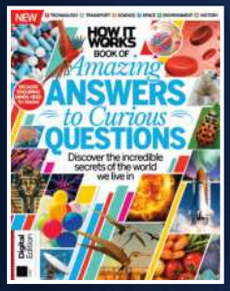

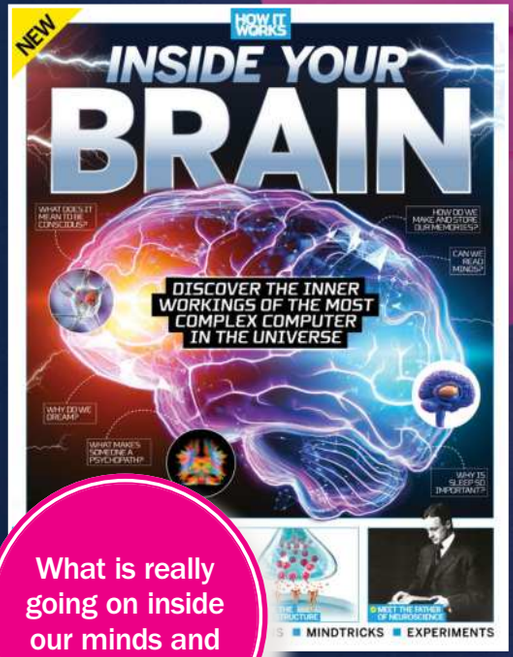

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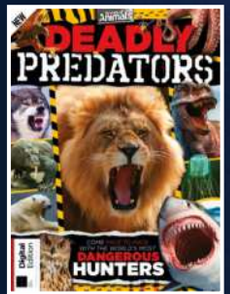

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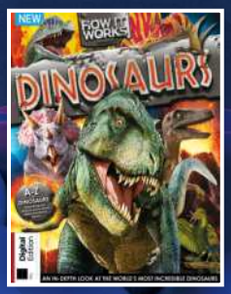

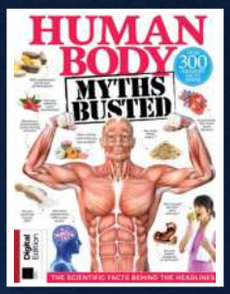

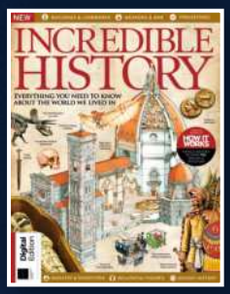

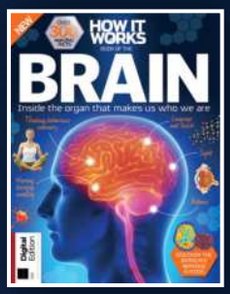

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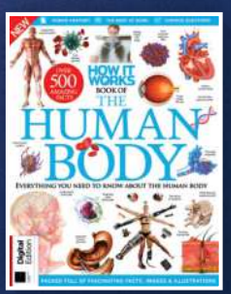

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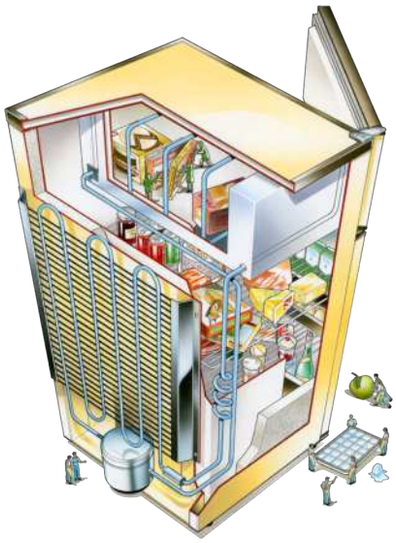

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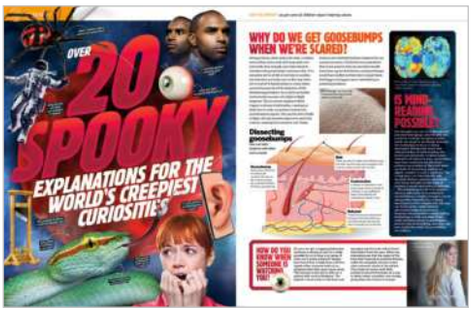

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